Final Technical Report: Next Generation Integrated PV Products Cost and Workflow Analysis

Jeff Cook,[1] Sushmita Jena,[1] Minahil Sana Qasim,[1] and Eric O'Shaughnessy[2]

1. National Renewable Energy Laboratory
2. Clean Kilowatts

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-6A20-86575
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Suggested Citation
Cook, Jeff, Sushmita Jena, Minahil Sana Qasim, and Eric O'Shaughnessy. 2023. *Final Technical Report: Next Generation Integrated PV Products Cost and Workflow Analysis*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-86575. https://www.nrel.gov/docs/fy23osti/86575.pdf.

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NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

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FINAL TECHNICAL REPORT (FTR)

Federal Agency:	U.S. Department of Energy
Award Number:	37330
Project Title:	Next-Generation Integrated PV Products Cost and Workflow Analysis
Recipient Organization:	National Renewable Energy Laboratory
Project Period:	01/01/2021–03/31/23
Principal Investigator (PI):	Jeffrey J. Cook, Ph.D. Renewable Energy Market and Policy Analyst Jeff.cook@nrel.gov 720-610-1150
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Certifying Official (if different from the PI or BC):	N/A

Jeff Cook 4/30/23

Signature of Certifying Official **Date**

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1 Project Summary

Residential photovoltaic (PV) costs have fallen consistently for over a decade (Ardani et al. 2018). The U.S. Department of Energy (DOE) subsequently developed a new residential PV cost target for 2030 of $0.05/kilowatt-hour (SETO 2023). Ardani et al. (2018) concluded that roofing-integrated PV (RIPV) products may be key to achieving the target for both new construction and retrofit residential PV.

In RIPV, the PV product is incorporated into or replaces the roofing material. RIPV systems can use conventional crystalline or thin-film technologies, may be aesthetically attractive alternatives to traditional racked and mounted PV systems, and may increase building property values (Cook et al. 2023). These products also have the potential to provide customer acquisition, labor, and equipment cost savings over traditional racked and mounted residential rooftop PV. Several companies have recently introduced RIPV products (Cook et al. 2023). In 2022, data from the state of California, the largest solar market nationwide, showed Tesla was the market leader, representing 94% of RIPV capacity installed that year through its Solar Roof offering (Feldman et al. 2023).

In this project, the National Renewable Energy Laboratory (NREL) analyzed three research questions:

1. How do current RIPV products compare to racked and mounted PV in terms of costs, installation times, and processes?
2. How are RIPV products installed, and are there opportunities for cost savings?
3. What are the key barriers to expanding market opportunities for integrating solar and roofing products?

In this project, we explored residential RIPV cost reduction opportunities by analyzing installation processes. Our study documented residential RIPV installations at two reroofing sites (20.52 kilowatts) and the equivalent of nine new construction sites (71.75 kilowatts) in California through a methodology known as a time and motion study. We also conducted 15 interviews with subject matter experts to identify barriers and solutions to maximize these products' market penetration.

2 Project Objectives and Outcomes

NREL addressed the three research questions through desk and field research. The desk research was utilized to address all three questions, whereas the field research was expressly targeted at questions 1 and 2, including identifying the installation process and potential cost savings opportunities in that workflow process.

NREL's desk research included requesting data on costs, deployment, and installation practices for as many RIPV manufacturers as NREL could locate (six RIPV manufacturers). NREL also relied on publicly available data to identify the scope of the PV market. Finally, NREL conducted interviews with 15 experts across 11 organizations to identify opportunities, barriers, and solutions to maximize residential RIPV deployment nationwide. Interviewees included representatives from various building-integrated PV (BIPV) product manufacturers (including RIPV manufacturers), solar installers, roofers, trade associations, and academics, among others. Interviewees were also invited to join a technical advisory group (TAG) to guide this research effort. The TAG comprised 17 participants from 15 organizations. The TAG met quarterly and provided feedback on the entire project, including our three research questions.

The data collected reflected that residential RIPV has underperformed relative to market deployment projections (Cook et al. 2023; Heinstein et al. 2014), and market uptake remains low compared to conventional rooftop PV. According to data from Barbose et al. (2021), residential BIPV installations accounted for as much as 1% of all residential rooftop PV installations from 2008–2010, but BIPV market shares subsequently declined through 2016. Residential BIPV market shares have since increased, growing from a low of around 0.005% in 2016 to about 0.4% in 2021 (Cook et al. 2023).

To complete our field research, we employed a time and motion methodology. A time and motion study is a method for analyzing the time spent on discrete tasks to complete a process. Time and motion studies have been applied to analyze a variety of processes. Most relevant for our context is the use of time and motion studies to analyze labor productivity in industrial processes. Time and motion studies of labor productivity can be used to identify time- and cost-saving opportunities that can be achieved by accelerating slow steps or eliminating redundancies.

To carry out the time and motion study, NREL generated an alpha data collection protocol to complete the observations and to serve as a basis to replicate the analysis for future studies. The final data collection/observation protocol is publicly available in the NREL Data Catalog: https://data.nrel.gov/submissions/212.

Our time and motion study breaks the RIPV installation process into four steps: (1) staging, unloading, and roof preparation; (2) underlayment(s) (the material laid between the roof shingles and roof deck); (3) flashings and PV installation; and (4) wiring and monitoring. We measure the time required for each step in terms of worker-hours (representing an hour of labor from a single worker). We further normalize the process time by dividing worker-hours by kilowatts (kW) of system capacity.

This analysis revealed many important findings that are described in detail in Cook et al. 2023. Here, we highlight some of the most critical findings regarding the installation process and timeline, how this compares to traditional racked and mounted PV, and a summary of cost reduction opportunities.

The most time-intensive step of the installation process was installation of flashings and PV. This step took around 2.4 worker-hours per kW on average and accounted for around 60% of the process time for an average installation. On average, the total installation process took about 6.4 worker-hours per kW at the reroofing sites and 3.5 worker-hours per kW at the new construction sites. For comparison, a previous time and motion study documented a time of 6.9 worker-hours per kW for conventional racked and mounted rooftop PV (see Figure 1). The shorter RIPV installation times are consistent with previous studies suggesting that RIPV could be installed faster than conventional rooftop PV (Cook et al. 2023). However, this is based on an analysis of installing a traditional racked and mounted PV project prior to 2014, and it is likely that installation practices have improved since then.

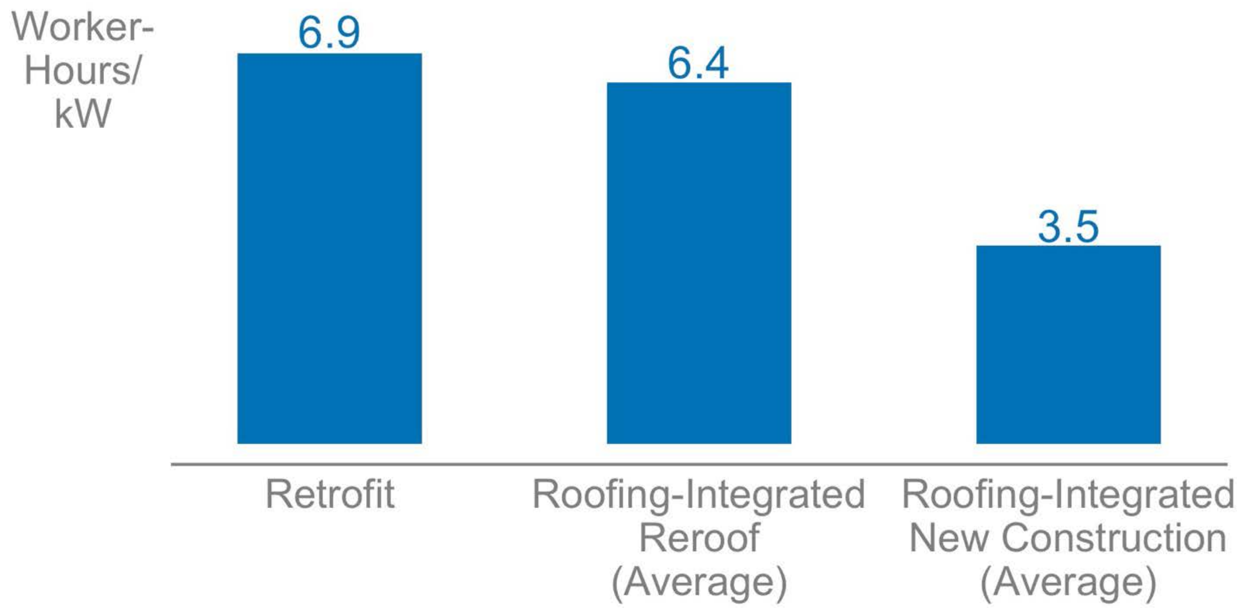

Figure 1. Comparison of average total installation times in worker-hours per kilowatt hour across system types (recreated from Cook et al. 2023)

The time and motion results and feedback from interviewees provide insights into potential residential RIPV cost reduction opportunities. Several interviewees suggested that RIPV products would be more efficient if PV installation was more fully integrated into the roofing/construction industries, which currently use separate supply chains and skill sets. Further integration could reduce supply chain delays and labor force redundancies.

The key milestones of this project are summarized below.

Table 1. Project Milestones

Milestone	Delivery Date
Technical advisory group established	3/31/21
Draft alpha observation protocol developed	3/31/21
Data from manufacturers and installers collected	6/30/21
Revised alpha observation protocol developed	6/30/21
First set of observations at installer sites completed	9/30/21
Beta observation protocol finalized	12/31/21
External market intelligence gathered	12/31/21
Outreach and engagement plan completed	3/31/22
Second set of observations at installer sites completed	6/30/22
Report on market opportunities for roofing-integrated solar products finalized	9/30/22
Results disseminated per the outreach and engagement plan	9/30/22

3 Lessons Learned

This research was designed to serve as a foundation for additional work in RIPV and BIPV technologies broadly. For these subsequent efforts, we offer a series of lessons learned from this research project, as summarized below.

Technical Advisory Group

We developed a technical advisory group (TAG) of a diverse set of stakeholders, including RIPV manufacturers, installers, trade associations, roofers, academics, and other subject matter experts. We found this TAG to be immensely valuable in shaping our research design, outcomes, and deliverables. For example, NREL generated a time and motion study protocol based on the installation process for a traditional racked and mounted PV installation. The TAG was critical in helping the team refine this protocol to align with the installation process for RIPV, ensuring the team was equipped to complete the time and motion study once in the field. The TAG also encouraged us to track roof planes, temperatures, PV array designs, and subarray quantities as critical variables that may influence timelines. Without the TAG's input, we may not have considered these variables and/or collected the relevant data. In addition, the TAG was critical in helping identify subject matter experts for our interviews and securing partners for installations. A key takeaway is that, projects in this area, and likely others, could benefit from incorporating diverse perspectives throughout their research efforts.

In this effort, we also identified that it was valuable to meet monthly at the start of the TAG to help shape our research scope, but after that, quarterly meetings were sufficient to continue to gain feedback from the TAG. Though we typically met quarterly, we only met with the TAG when we had new material to present. As such, we skipped some quarterly meetings in the latter half of the project period to reduce participants' time commitment.

Time and Motion Study Replication

As noted, NREL elected to use a time and motion study methodology for this project. This method is designed to analyze the time spent on discrete tasks, thereby assessing labor productivity. Time and motion studies of labor productivity can be used to identify time- and cost-saving opportunities that could be achieved by accelerating slow steps or eliminating redundancies (Cook et al. 2023). Though valuable, the process to carry out a time and motion study can be lengthy. In this case, we realized some cost savings by breaking our observations for new construction into two parts, and then normalizing the results, so the team was not required to do two separate visits at the same site. This could help other researchers reduce the cost of this exercise. The team also attempted to work with manufacturers and installers to carry out the time and motion studies on behalf of the research team. However, labor shortages, lack of videography expertise, equipment failures related to high ambient temperatures, and the complexity of the observation processes made it difficult for partners to provide sufficient data for the study. The research team may be more successful if they find pathways to streamline their own time and motion research design, as opposed to attempting to crowdsource the data from partners.

RIPV Installation Cost Assessments

This study initially sought installation cost data from six RIPV providers. The cost data that NREL received was disparate, and the team was unable to organize the data to provide a consistent, accurate reflection of RIPV costs. Further, our limited resources made it difficult to generate a cost model that also accounted for the cost of roof installation. This is in part because existing roofing cost calculators are based on dollars per square foot, whereas most solar design, cost, and production tools are based on dollars per kilowatt-hour. NREL was unable to find any publicly available tools that incorporated both components into a single platform. At the same time, it is essential to merge these calculations to reflect the true cost of RIPV relative to installing solar and/or a new roof alone. Given that NREL was unsuccessful in collecting cost data, the best path forward to assess RIPV costs may be to develop an RIPV cost model that accounts for roofing costs, and then provide that model to RIPV stakeholders for review and input. The team can then verify the accuracy of the tool through interactions with stakeholders, which has proven to be successful in NREL's benchmark cost modeling for other technologies, including racked and mounted PV.

4 Path Forward

There are a variety of pathways by which to expand the research base for RIPV. Our study was based on a relatively small sample of field sites and contractors working exclusively in California. Future work could expand on these results by applying time and motion analysis or similar methodologies to a larger and more diverse sample of technologies (roofing-integrated and conventional), sites, contractors, and geographies. Further, although we compared our results to previous research on conventional rooftop PV, our study lacked a true "control" group with which to compare results. Future research could more systematically evaluate process and time differences between different PV installation methods, such as conventional rooftop PV on existing buildings, conventional rooftop PV during reroofing, conventional rooftop PV during new construction, RIPV during reroofing, and RIPV during new construction. A systematic analysis of distinct PV installation methods will help identify specific ways to hone installation processes, reduce costs, and maximize the role of these products in building decarbonization. Finally, this project was not able to develop a cost model for RIPV as compared to traditional PV. This is a critical next step for providing stakeholders with the information necessary to inform their deployment decision-making.

5 Inventions, Patents, Publications, and Other Results

NREL has published one technical report and one data set, as summarized below.

Technical Reports

Cook, Jeffrey J., Sushmita Jena, Minahil Sana Qasim, and Eric O'Shaughnessy. 2023. *Observations and Lessons Learned From Installing Residential Roofing-Integrated Photovoltaics*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A2085230. https://www.nrel.gov/docs/fy23osti/85230.pdf.

Data Set

NREL. n.d. "Observations and Lessons Learned in Residential Roofing Integrated Photovoltaics." https://data.nrel.gov/submissions/212.

6 Project Team

The project team is summarized in Table 2.

Table 2. Project Team and Roles

Name	Role	Organization
Jeffrey Cook	Principal Investigator	NREL
Sushmita Jena	Data Analyst	NREL
Minahil Sana Qasim	Data Analyst	NREL
Eric O'Shaughnessy	Data Analyst	Clean Kilowatts

7 References

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