NATIONAL LABORATORY OF THE ROCKIES

Solar Photovoltaics Resilient Fasteners Levelized Cost of Energy (LCOE) Tool

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Introduction

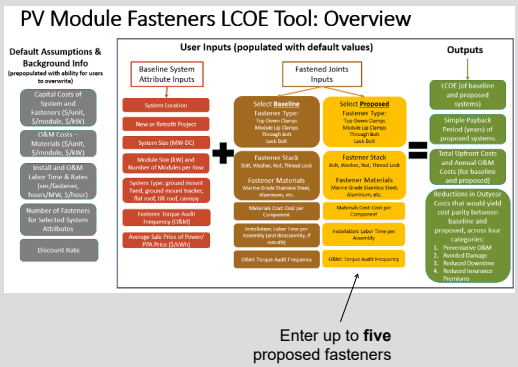
- Solar Photovoltaic (PV) module fasteners are a **common structural failure point [1-2]**, especially in **high wind events.**
- Fasteners that fail less may have a **higher upfront cost**, but this investment can **pay off in savings** from less frequent torque audits (which reduces O&M costs), reduced system damage, decreased system downtime, and potentially lower insurance premiums.

PV system damage seen in Guam after Typhoon Mawar included: insufficient module clamping leading to modules releasing in a cascading fashion (left), loose module clamps laying undamaged on roofs after rotating out of racking and releasing modules (middle), and damage to modules from debris—likely another PV module (right). Photos by James Elsworth, NLR [1].

Objective

- Develop a Microsoft **Excel tool to evaluate different PV module fasteners** for either a new or retrofit PV system.
- The tool compares **upfront and outyear costs** to determine the expected **life cycle cost and simple payback periods** of different fastener options.
- The tool also **outputs the life cycle cost reductions needed to offset any upfront cost premiums.**
- Purpose: highlight where there is a **financial case for better fasteners**; outputs can serve as decision aids for users.

LCOE Tool Methodology



Scenarios & Results

Scenario 1. Standard Through Bolt Compared to Locking Through Bolt Options

System inputs:
- 1 MW new construction
- 550W modules
- Ground-mount tracker
- 6.5 cents/kWh sale price of power

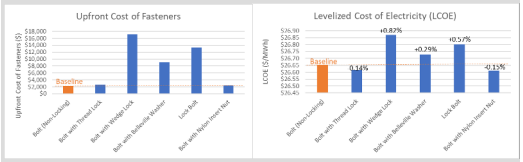
Baseline Fastener
Non-Locking Bolt*

Photo from James Elsworth, NLR.

vs.

Proposed Fasteners
1. Bolt + Thread Lock
2. Bolt + Wedge Lock
3. Bolt + Belleville Washer
4. Lock Bolt
5. Bolt + Nylon Insert Nut

*With annual fastener torque audit



Life cycle cost reductions needed to offset any upfront cost premiums compared to the baseline non-locking bolt:

Item	Bolt with Thread Lock	Bolt with Wedge Lock	Bolt with Belleville Washer	Lock Bolt	Bolt with Nylon Insert Nut
Upfront Cost Premium (compared to baseline fasteners)	$406	$14,838	$6,877	$10,988	$171
Equivalent reduction in lifetime O&M costs	0.2%	3.7%	1.7%	2.8%	0.1%
Equivalent avoided lifetime lost production	0.013%	0.464%	0.186%	0.799%	0.005%
Equivalent avoided system lifetime damage repair costs	0.03%	1.15%	0.69%	0.86%	0.01%
Equivalent reduction in insurance costs*	1.22%	44.54%	20.49%	32.98%	0.52%

*Assuming insurance costs are 0.25% of upfront capital system costs

Higher upfront costs from using a wedge lock are equivalent to **1.15% of the system *not* being damaged** over its lifetime

Scenario 2: Top-Down Clamps vs. Other Options

System inputs:
Same system inputs as Scenario 1

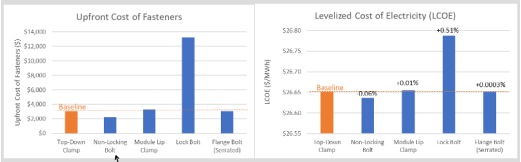
Baseline Fastener
Top-Down Clamp*

Photo from James Elsworth, NLR.

vs.

Proposed Fasteners
1. Non-Locking Bolt*
2. Module Lip Clamp*
3. Lock Bolt
4. Flange Bolt (Serrated)*

*With annual fastener torque audit



Non-Locking Bolt has lower upfront costs than Top-Down Clamp

Item	Non-Locking Bolt	Module Lip Clamp	Lock Bolt	Flange Bolt (Serrated)
Upfront Cost Premium (compared to baseline fasteners)	-$833	$216	$10,155	-$5
Equivalent reduction in lifetime O&M costs	-0.4%	0.1%	4.6%	0.0%
Equivalent avoided lifetime lost production	-0.023%	0.006%	0.277%	0.000%
Equivalent avoided system lifetime damage repair costs	-0.06%	0.02%	0.79%	0.00%
Equivalent reduction in insurance costs*	-2.50%	0.65%	30.48%	-0.01%

*Assuming insurance costs are 0.25% of upfront capital system costs

Higher upfront costs from using a lock bolt are equivalent to a **4.6% reduction in preventative O&M costs** (such as torque audits)

Call for Collaboration!

- Have your PV sites experienced module fastener failures, or are you interested in exploring different fasteners and their costs?
- We're offering an **opportunity to beta test the tool**. You'll use the tool and provide feedback, and we'll provide free analysis.
- Fill out the form below to express interest (or email bonnie.powell@nlr.gov and james.elsworth@nlr.gov)

https://forms.office.com/g/3aXswmgBCR

Conclusion & Future Work

- The **financial case** for stronger fasteners can be made using this LCOE tool.
- Through bolts are typically more resilient than top-down clamps [1-2]; there are options with a lower LCOE and cases where the upfront cost would pay off from minimal avoided damage (or reduced O&M).
- Future work includes incorporating **expected damage** costs from field data (including data from [3]), incorporating **risk level** of the site location to high winds, and partnering with **industry** to update cost data and assumptions.

Failed top-down clamps in Guam as a result of Typhoon Mawar. Photos from James Elsworth, NLR.

References

[1] Elsworth, James, Otto Van Geet, Charles Kurnik, and James Salasovich. 2024. *Solar Photovoltaic (PV) Damage Assessment After Typhoon Mawar: Findings and Recommendations for Resilient PV on Guam.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5R00-89629. https://www.nrel.gov/docs/fy25osti/89629.pdf.

[2] Burgess, C., Goodman, J., Dabbagh, K., Lopata, M., Miller, D., Needham, C.,and Oudheusden, F. *Solar Under Storm Part I: Select Best Practice for Resilient Ground-Mount PV Systems with Hurricane Exposure.* RMI, 2020. https://rmi.org/insight/solar-under-storm/.

[3] Perry, K., Jordan, D. C., and Nguyen, Q. Assessing the Impacts of Extreme Weather Events on Photovoltaic Installations Using Remote Sensing Imagery. Progress in Photovoltaics, 33 (9) 1012-1023. 2025. https://doi.org/10.1002/pip.70001.

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