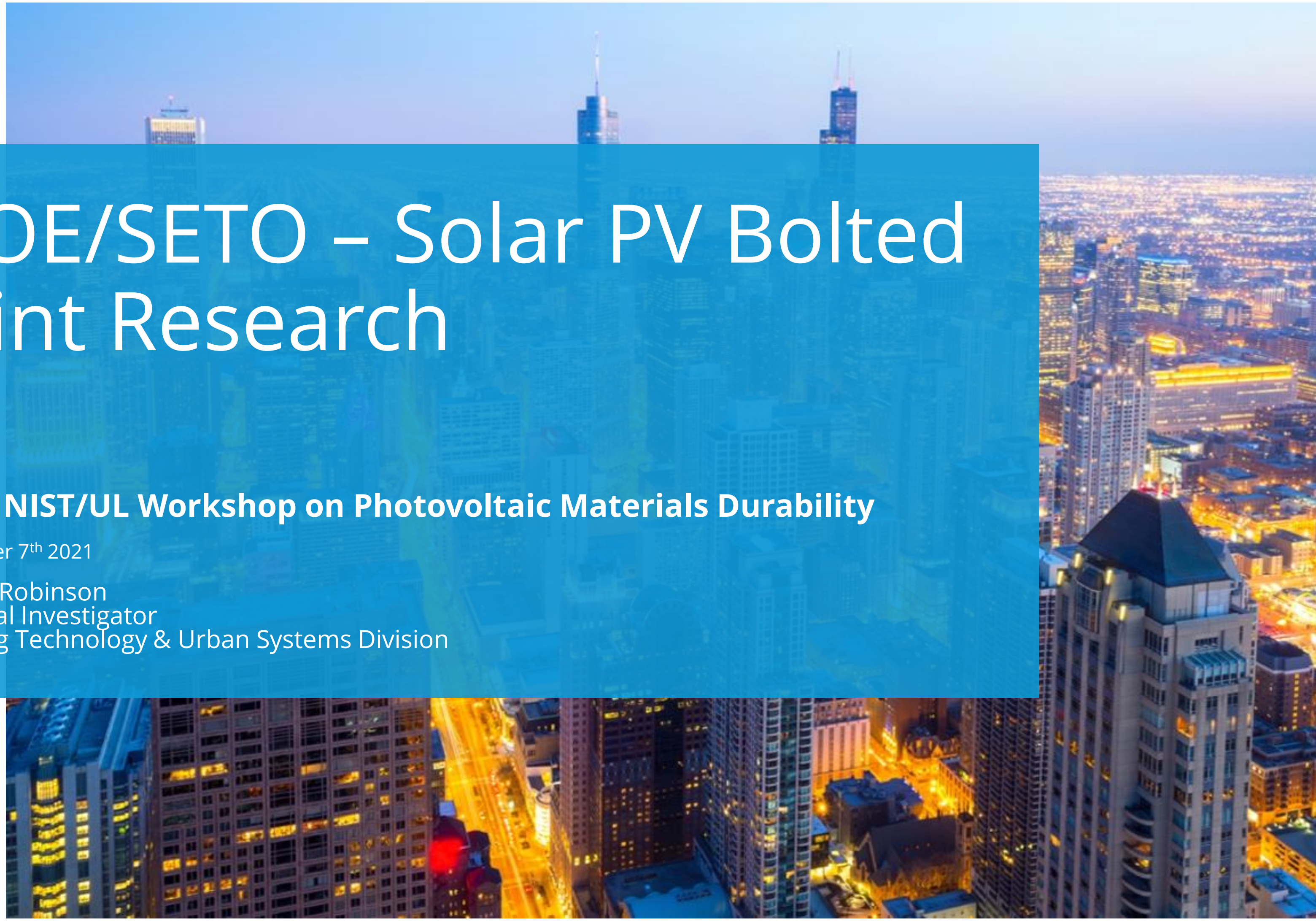

DOE/SETO – Solar PV Bolted Joint Research

2021 NIST/UL Workshop on Photovoltaic Materials Durability

December 7th 2021

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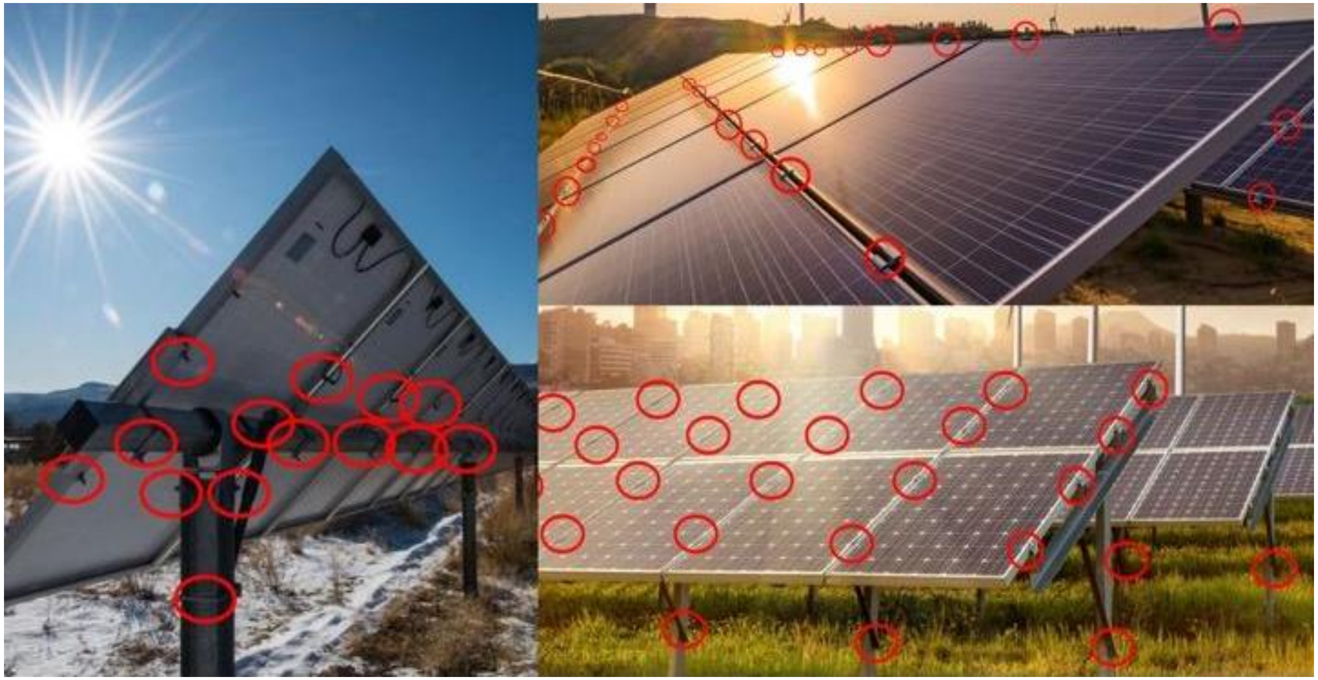
Building Technology & Urban Systems Division

Presentation Outline

1. **Background**
2. **Proposed Research**
3. **Industry Engagement**
   - **Feedback**
   - **Engagement**

Critical Bolted Joints



"an assembly of components (fasteners, clips, washers, brackets) used to fastened structural joints which includes module attachment and racking and tracker interconnections not otherwise covered by AISC 360"

Background

- Failures with critical bolted joints appear common
- Bolted joints have systemic impact on array stability
  - Wind induced vibrations and frequency
  - Loss of modules
- Solar systems typically have several “critical” bolted joints that are unique
  - Unique designs
  - Highly dynamic forces
- Design guidance based on test data and from transferable knowledge is lacking in solar PV structures
- DOE/SETO Lab directed research awarded

DOE/SETO Funded Research

Objectives:

- Mature bolted joint technologies as used in solar PV structures
  - High volume, low cost, high reliability
- Produce data on extent and characteristic of failures
  - LCOE, longevity, performance and durability to weather events
- Characterize the technical/engineering root cause failures of bolted joints
- Produce design guidance for key stakeholders
  - Short-term – immediate usable guidance
  - Long-term – SDO influence through data
- Provide empirical evidence to provide the credibility needed to influence the standards develop organizations (SDOs)

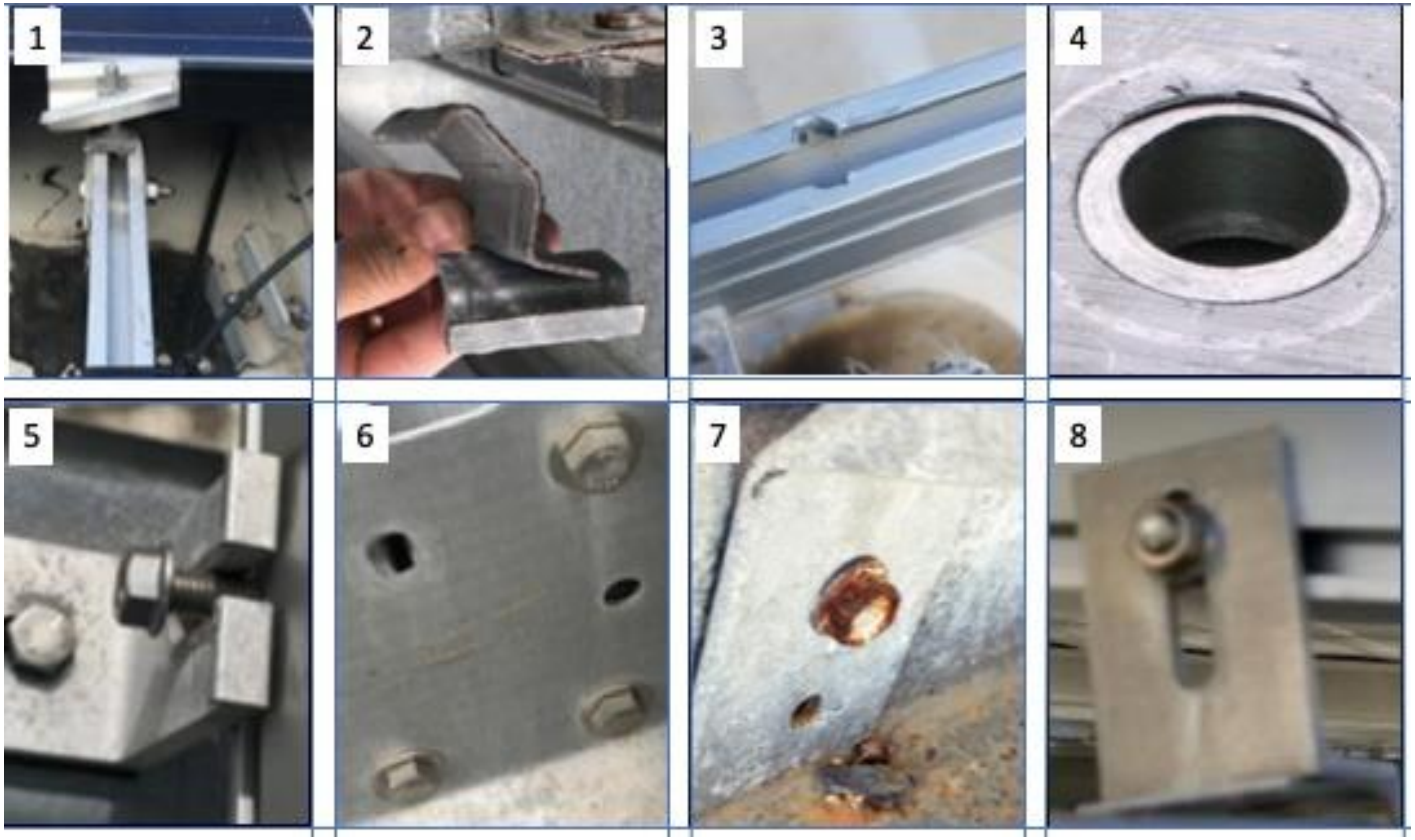
Meet The Team

James Elsworth, National Renewable Energy Labs		Actively engaged in multiple PV severe weather and system resilience topics. Published paper on cost impacts of weather hardening and will lead the cost accounting efforts to understand LCOE impacts.
Jon Ness, Matrix Engineering		Engineer and SME with experience in the design, validation and installation of dynamically loaded bolted joints including those used in solar PV systems. Consultant to PV system owners, examining root cause failures and engineering bolted joint retrofits.
Dr. Becker University of California Berkeley		Assistant Professor, Department of Civil and Environmental Engineering. Conducts research on a wide range of structural engineering topics and is supported by two major laboratory facilities capable of full-scale dynamic testing.

Meet The Team

Chris Needham, FCX Engineering		Aeroelastic engineering, product and retrofit designs. Backgrounds as engineer with racking product designers and consultants to system owners.
Frank Odenhouse, FCX Engineering		Engineer and SMEwith solar PV structures and bolted joints. Backgrounds as engineers as racking product designers and consultants to system owners.
Joe Cain, Solar Energy Industries Association		Engaged with racking manufacturers, codes and standards and has co-authored two seminal SEAOC guidance documents.
George Kelly, American Renewable Energy Standards and Certification Association		Expert on module reliability, certifications and qualification testing, with leadership roles in the development of international standards through IEC and ASTM. Founding member of the American Renewable Energy Standards and Certification Association (ARESCA), formed in 2015 to foster renewable energy standards and certification efforts.

Bolted Joints – Example Failures



Interactions – Bolted Joint & Structures

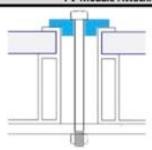
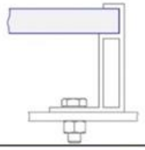
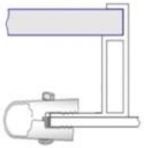
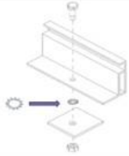
- Bolted joint determinant of structural integrity of rack
- Rack structural elements influence bolted joint durability
- Feedback loop – death spiral

Task 2.1 – Stakeholder Map

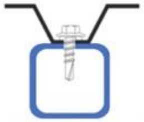
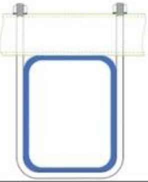
- **Objectives** – Finalize stakeholders and identify “care abouts”
  - Make sure team understands factors that each stakeholder considers in decision making.
  - Provide insight to survey step
- **Methods** – Interview stakeholders to understand relevant factors

Task 2.1 Classification System Bolted Joints

Module Mounting

Joint Type	Image of Joint Type	Vulnerabilities
PV Module Attachment		
Top Down Clamp Joints		1) Behaves as a soft joint, the applied loads are reacted entirely by the bolt. 2) Transverse slip in joint results in instability of the top down clamp. 3) Lack of redundancy in system, so prone to single point failure. (i.e. detachment of one module releases second module) 4) Initial clamp load acheived during tightening is critical to joint performance.
Short Through Bolt Joints		1) Initial clamp load acheived during tightening is critical to joint performance. 2) Small fasteners (i.e. 3/8" or less) with short grip lengths are prone to relaxation and need for repeated retightening.
Module Clamp Joints		1) Initial clamp load acheived during tightening is critical to joint performance. 2) Clamp load achieved in the joint interface is often insufficient to develop friction grip in joint, as a result, the design is prone to slip. 3) Slip in joint results in plastic deformation at the teeth and the further loss of clamp load.
Joints with Electrical Bonding Devices		1) Initial clamp load acheived during tightening is critical to joint performance. 2) Small fasteners (i.e. 3/8" or less) with short grip lengths are prone to relaxation and need for repeated retightening. 3) Bonding device causes high contact stress the location of contact, resulting in plastic creep and the loss of clamp load.

Frame Assembly

Joint Type	Image of Joint Type	Vulnerabilities
PV Racking		
Soft Joints		1) Initial clamp load acheived during tightening is critical to joint performance. 2) Soft joint limits the clamp load which can be achieved before collapse of thin stuctural members occurs.
Joints Connected with Self-Tapping or Thread Forming Screws		1) Limited thread engagement makes this connection prone to stripping. 2) Not practical to control the preload achieved through torque tightening - typically there is a wide range of preload scatter.
Non-Redundant - Tension/Compression Members		1) Initial clamp load acheived during tightening is critical to joint performance. 2) Joint prone to reverse transverse slip - resulting in self-loosening and loss of clamp load. 3) Prone to single point failures resulting in cascade of secondary failures in other joints in racking system.
PV Trackers		
Joints with Square U-bolt Clamps		1) Initial clamp load achieved during tightening is critical to joint performance. 2) Thin wall tubes and square u-bolt design limits the clamp load that can be achieved during tightening. 3) 'Square bend' in bolt creates a high stress concentration which is prone to fatigue failure.

Task 2.1 - Surveying

Filling data gaps and characterizing fastener failures.

- **Objectives** – address need for data to
  - Highlight bolted joints and issues for later research phases.
  - Fill a general need for failure data – highlights need to address issues and begins to describe what some of those issues are.

- **Methods** – phone interviews using structured survey methods
  - Survey will not elicit information that identifies specific locations, owners and product manufacturers

Task 2.2 Codes & Standards Gaps

- **Objectives –** Identify where existing codes and standards lack adequate requirements and instruction.
  - Highlight need for more data – inform later research
  - Identify sponsor for the guidance document
  - Influ
- **Methods -** Survey of existing codes and standards.
  - Present results at working group meetings to gain direct feedback
  - Use feedback to produce short article on gaps

Task 2.3 Transferable Knowledge

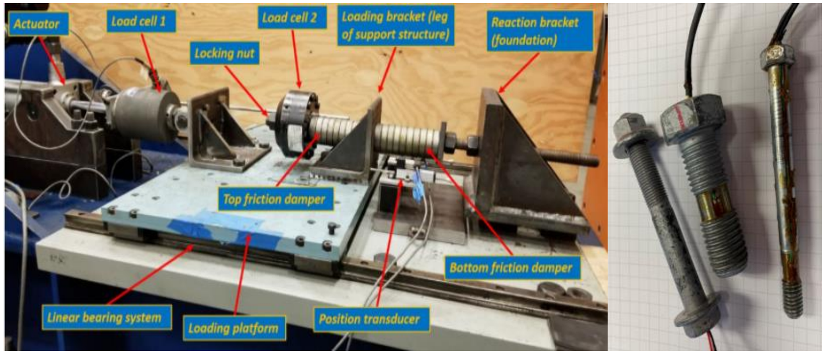
- **Objectives –** Identify existing engineering knowledge that can be directly applied to solar PV bolted joints
  - Down-select bolted joint types that may require testing – mysteries persist.
- **Methods -** Examine existing bolted joint engineering resources from such fields (transportation, buildings) for applicability to solar structures.
  - Present findings at working meeting
  - Seek input and incorporate
  - Produce short paper outlining results

Task 3.1 Modeling

- **Objectives -** Understand how solar structures are dynamically loaded.
  - Use values to inform later testing
- **Methods** – Use CFD modeling and available wind tunnel test data to develop validated models to depict loading on solar structures.

Task 3.3 Lab Testing

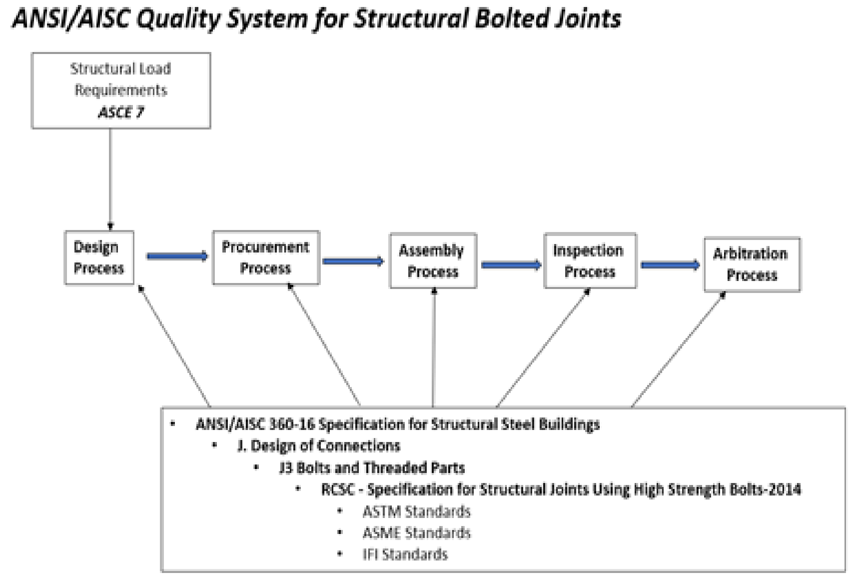
- **Objectives –** Test down-selected list of bolted joints.
  - Test bolted joints that have unique qualities, where transferable knowledge is not applicable
  - Establish test methods to be used by others
- **Methods –** Lab testing with jig of rams and strain gauges to simulate dynamic loading.
  - Use finite element analyses (FEA) to provide test validation



Task 4.1 Quality Management System

- **Objectives –** Develop quality management system (QMS) that can guide action from full life-cycle from design to arbitration process.

- **Methods –** Utilize well developed QMS from relevant industries.

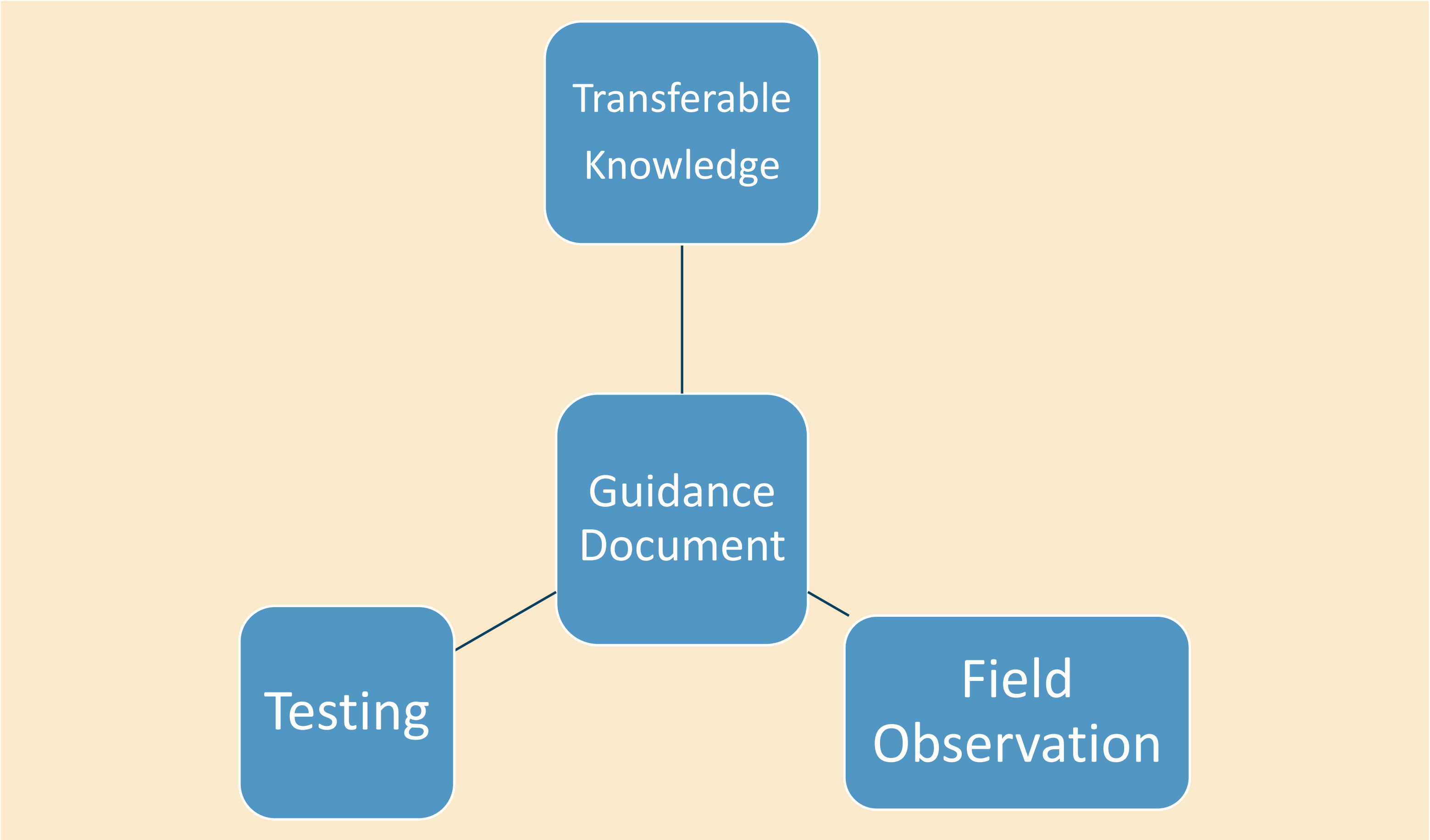


Task 4.3 LCOE Insights

- **Objectives – LCOE Impacts**
  - Understand LCOE impacts of failures
    - Direct costs e.g. rebuild, loss of production
    - Soft costs e.g. insurance premiums
  - LCOE impacts of better design choices
  - Match types of analysis used insurance and finance
  - Inform Guidance Document recommendations

- **Methods – Development of tools**
  - Development of spreadsheet tool usable by stakeholders

Task 4.4 Guidance Document



Guidance Document Uses

Product Designers

- Off-the-shelf racking
- Custom designs

Insurance and finance

- Assessing assets for investment
- Determining risk

Post event – engineering

- Engineering effective retrofits
- Insurance claim $

Standards Development Organizations (SDO)

Use for SDO committee work

Seeking Your Input

Three key areas – seeking input

1. Feedback on planned research
2. Survey contacts
3. Collaborations in research
4. Datasets that can be correlated

Contact

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