Accelerating PV Cost Reduction Through an Open-Source Software Ecosystem

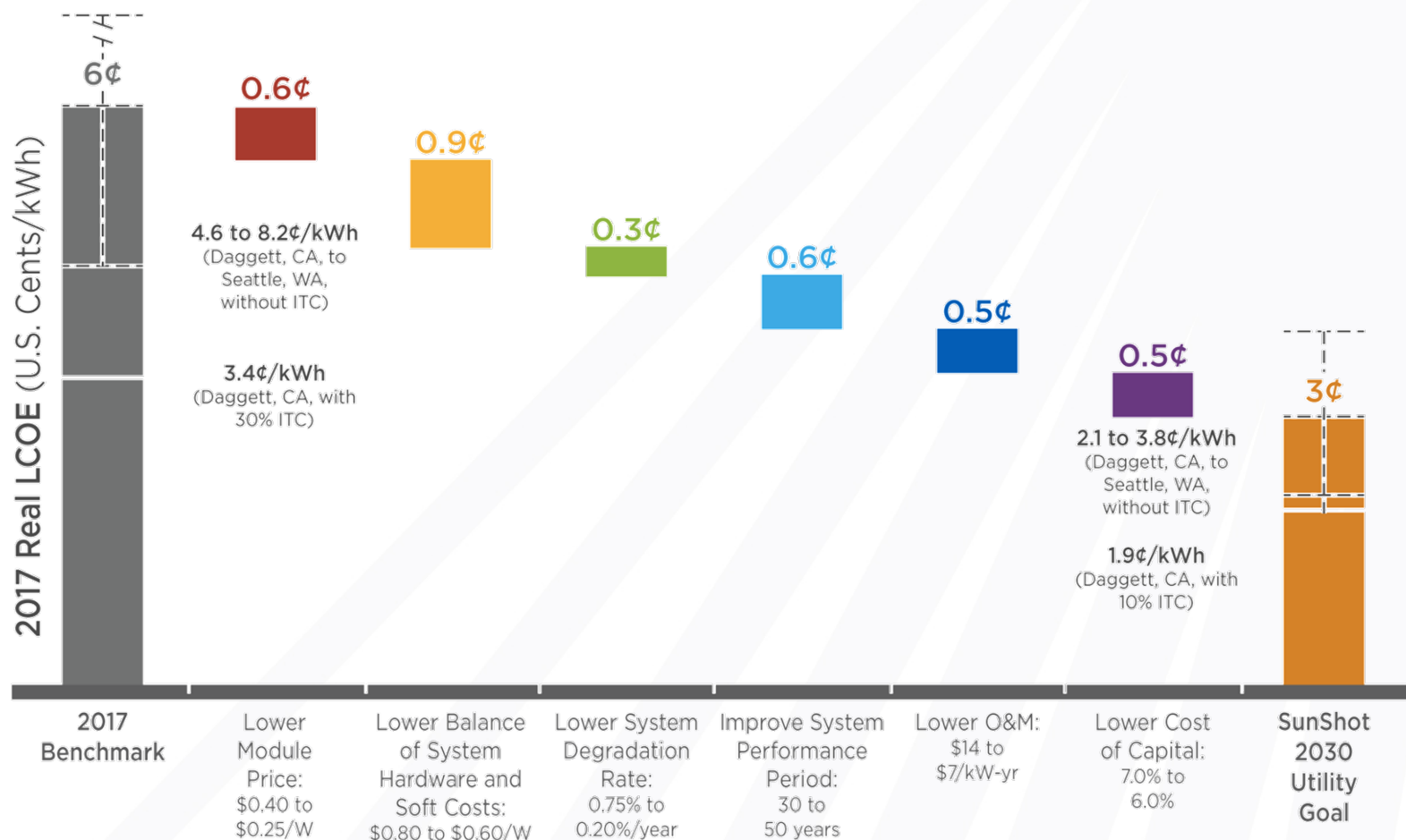PV Performance Modeling Collaborative

May 2, 2018

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Solar Energy Technologies Office

U.S. Department of Energy

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Outline

- DOE Cost Goals and Performance Modeling

- Supporting a Modeling Ecosystem

- Orange Button and Beyond for Data Standards

- Current Open-Source Modeling Tools

- DuraMAT as Collaboration Model
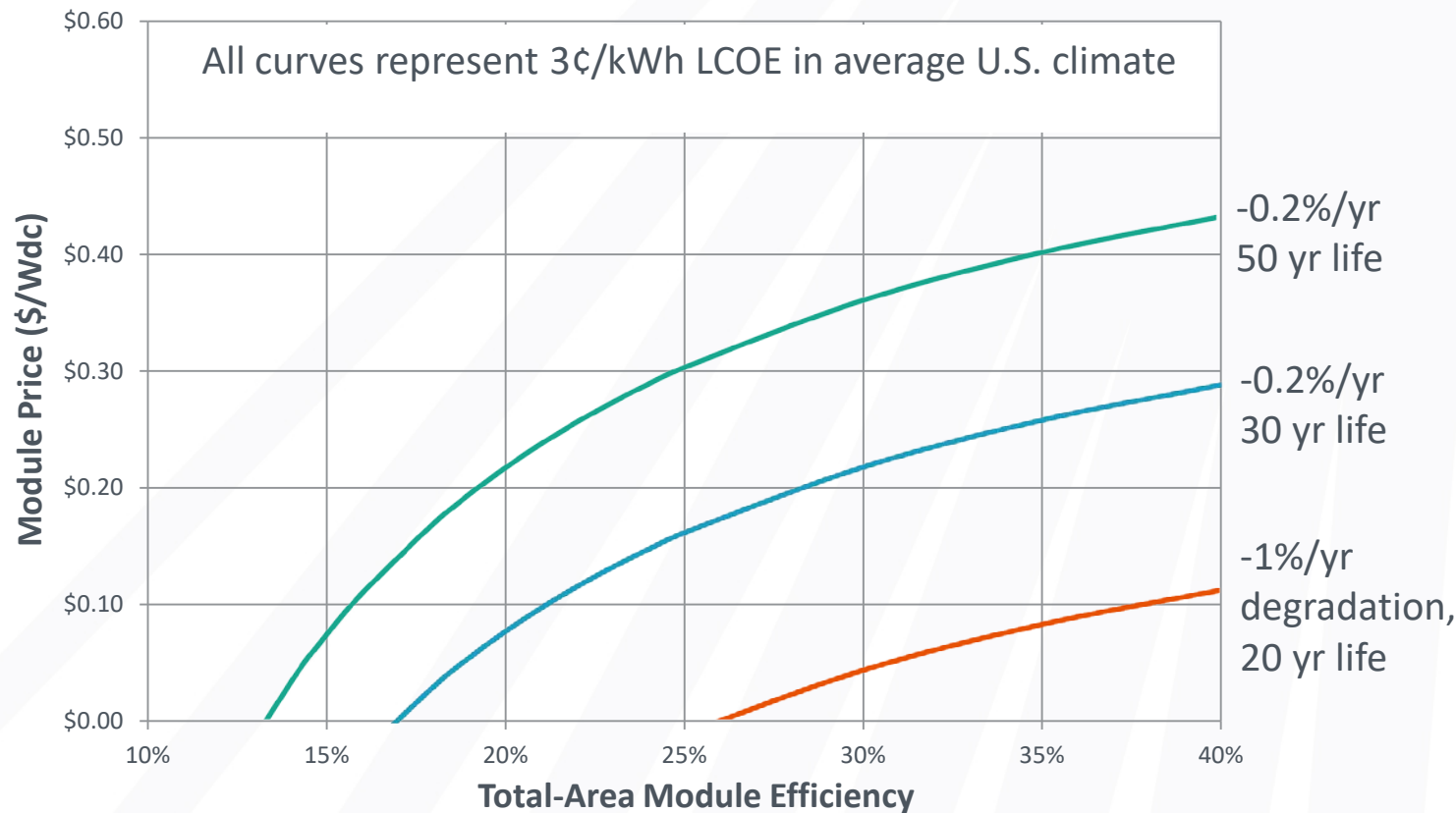
- Putting the Pieces Together

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SETO Cost Targets and Uncertainty in Energy Yield

Chart showing 2017 Real LCOE (U.S. Cents/kWh) with cost reduction steps:

- **2017 Benchmark**: 6¢
  - 4.6 to 8.2¢/kWh (Daggett, CA, to Seattle, WA, without ITC)
  - 3.4¢/kWh (Daggett, CA, with 30% ITC)
- **Lower Module Price: $0.40 to $0.25/W**: 0.6¢
- **Lower Balance of System Hardware and Soft Costs: $0.80 to $0.60/W**: 0.9¢
- **Lower System Degradation Rate: 0.75% to 0.20%/year**: 0.3¢
- **Improve System Performance Period: 30 to 50 years**: 0.6¢
- **Lower O&M: $14 to $7/kW-yr**: 0.5¢
- **Lower Cost of Capital: 7.0% to 6.0%**: 0.5¢
- **SunShot 2030 Utility Goal**: 3¢
  - 2.1 to 3.8¢/kWh (Daggett, CA, to Seattle, WA, without ITC)
  - 1.9¢/kWh (Daggett, CA, with 10% ITC)

- Reduced uncertainty in performance modeling,
  - Increase system performance, lower O&M / financing

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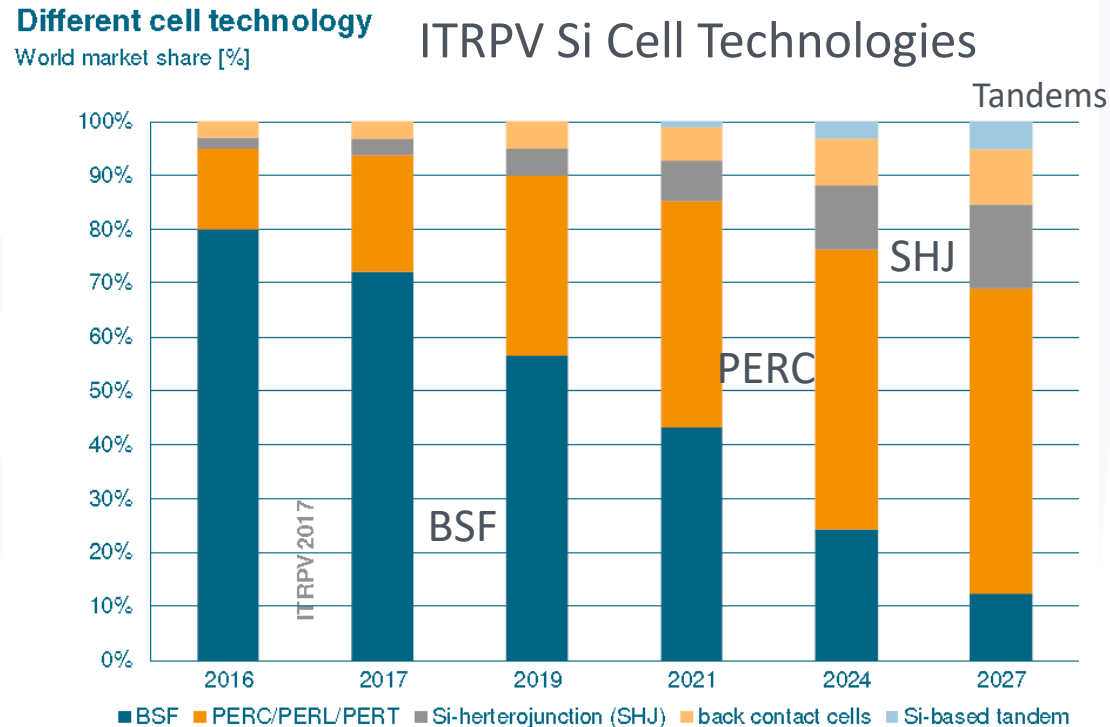U.S. Department Of Energy

Many Technology Pathways to $0.03/kWh

- Cost and performance tradeoffs open up numerous pathways.

- All pathways require sustained, multifaceted innovation.

All curves represent 3¢/kWh LCOE in average U.S. climate

-0.2%/yr 50 yr life

-0.2%/yr 30 yr life

-1%/yr degradation, 20 yr life

Module Price ($/Wdc) vs Total-Area Module Efficiency

Scenarios assume: 7% WACC, 2.5% inflation, $4/kW-yr O&M, 21% capacity factor

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High Performance PV Technologies

- The industry is moving rapidly toward PERC technologies

- Heterojunction, and IBC technologies will continue to higher performance

- Similar estimates for Bifacial modules and systems

Different cell technology
World market share [%]

ITRPV Si Cell Technologies

Tandems

SHJ

PERC

ITRPV 2017

BSF

Legend: ■ BSF ■ PERC/PERL/PERT ■ Si-herterojunction (SHJ) ■ back contact cells ■ Si-based tandem

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Evolution of Module and System Designs

- System performance and degradation models need to be updated to reduce risk of new technologies

  - New cell and module architectures
    - Degradation models for PERC, Heterojunction, etc.
    - Performance models for bifacial modules and systems
  - Anti-soiling, anti-reflection coatings
    - Durability and performance of module coatings
    - Spectral and angular dependence

- Require close interaction between innovations in module design and performance modeling and characterication

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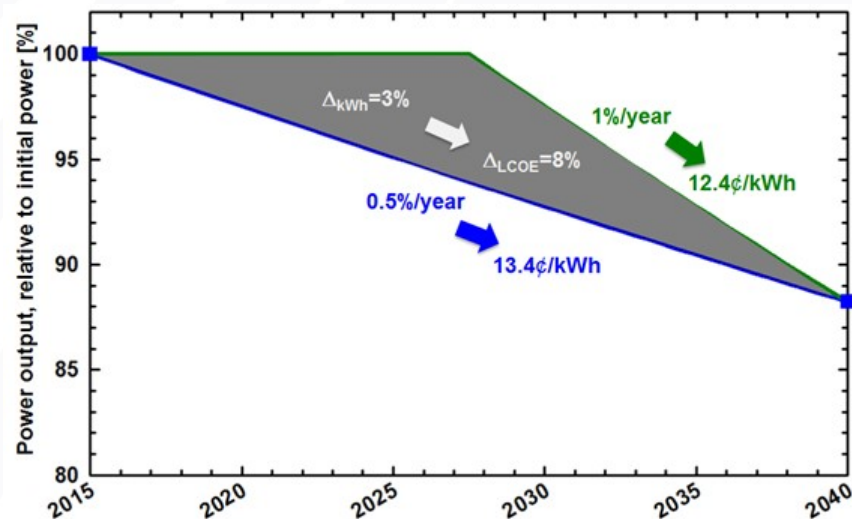
Uncertainty in System Performance

- Uncertainty in system performance leads to higher risk for PV developers, financiers and operators

- Exceeding these estimates provides increased revenues and system value

- Decreasing uncertainty can help to lower the cost of solar electricity

- DOE motivation is to support the field toward developing tools and data formats to reduce variability of PV system development estimates and field performance of PV systems

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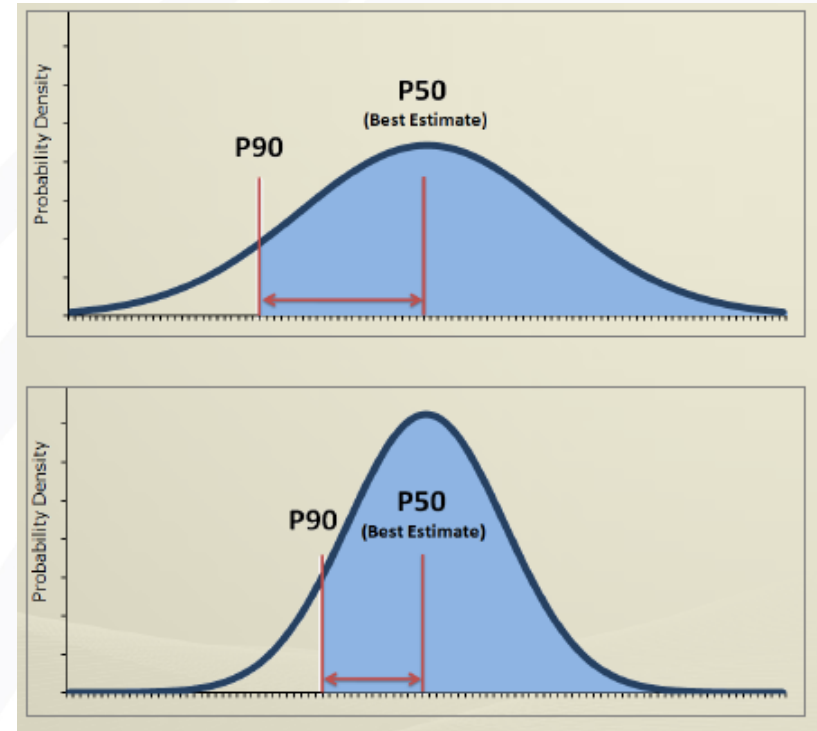
Data Format Standardization and Resource Databases

- Orange Button (Sunspec, NREL,…)
  - Industry-driven data standards to reduce market inefficiencies and lower costs
- NSRDB (NREL)
  - Serially complete collection of meteorological and solar irradiance data sets for US
- The Open PV Project (NREL)
  - Database of contributed public data for photovoltaic (PV) installation data for the US
  - Utilized by LBNL for their annual *Tracking the Sun* report
- PVDAQ – PV Data Acquisition (NREL)
  - PV performance data collected by NREL for systems throughout US

ORANGE BUTTON℠

Direct Normal Irradiance

kWh/m²/Day
> 7.5
7.0 to 7.5
6.5 to 7.0
6.0 to 6.5
5.5 to 6.0
5.0 to 5.5
4.5 to 5.0
4.0 to 4.5
< 4.0

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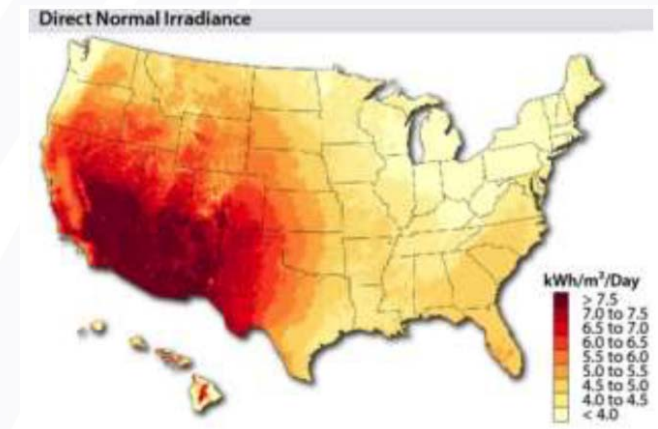
Available Performance Modeling Tools

- **PVLIB (Sandia)**
  - PV performance modeling functions for simulating performance of PV systems

- **SAM (NREL)**
  - Detailed performance and financial model to facilitate decision making

- **PVWatts (NREL)**
  - Basic solar modeling tool that calculates PV energy production based on minimal inputs

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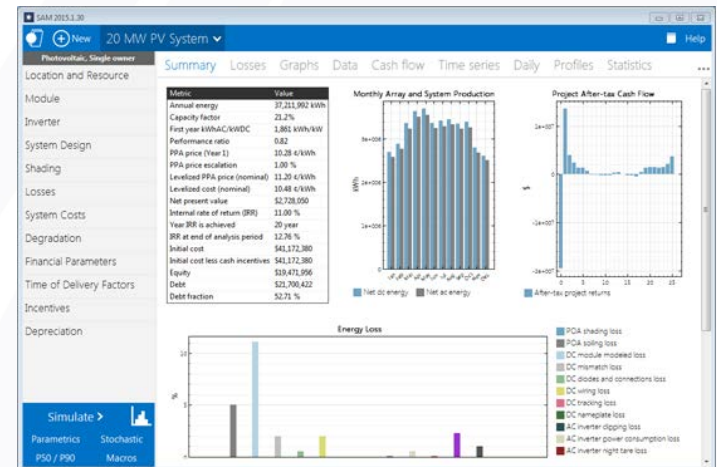
Available Performance Modeling Tools

- ## RdTools (NREL)
  - Analysis of photovoltaic time-series data, used primarily to evaluate system degradation rates
  - Uses PVLIB functions

- ## Pecos (Sandia)
  - Monitor system performance of time series data

- ## Bifacial Performance Models (Sandia, U. Iowa, NREL)
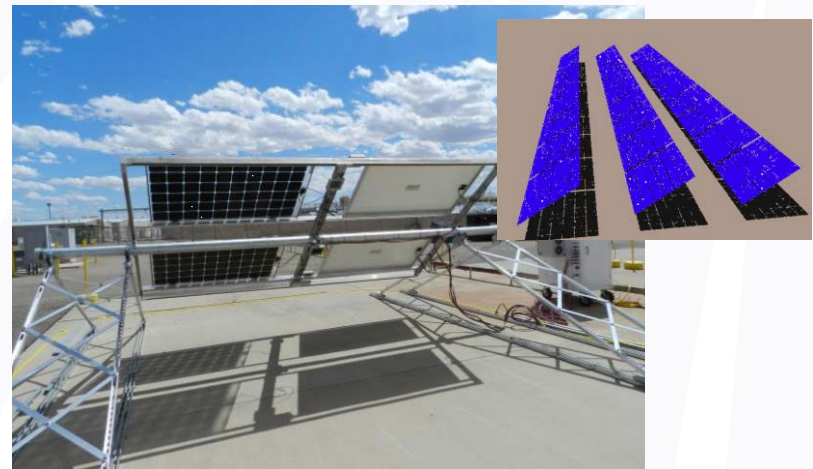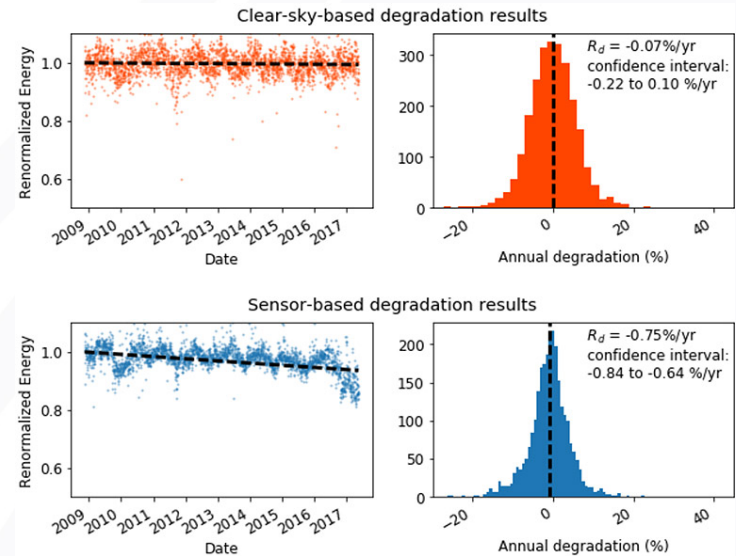
The DuraMAT Consortium – Durable Module Materials

- 5-year Energy Materials Network consortium focused on precompetitive research into **module packaging**
  - Teresa Barnes at NREL Director
  - Margaret Gordon at Sandia Deputy
- **Who Is Involved**
  - <u>PV industry</u>: R&D goals
  - <u>National Labs</u>: capability expertise
  - <u>Universities</u>: research infrastructure
- **Goal:** Accelerate PV module material design and improve durability
- **Industrial Advisory Board (IAB)**
  - 15 members, open to new members
  - Guides scope of projects and research focus
- Projects underway
  - 6 national lab capability development projects
  - 8 university research projects
  - 3 collaborative industry-lab projects, funded in 2017
  - 4 Spark projects (2 active, 2 selected)
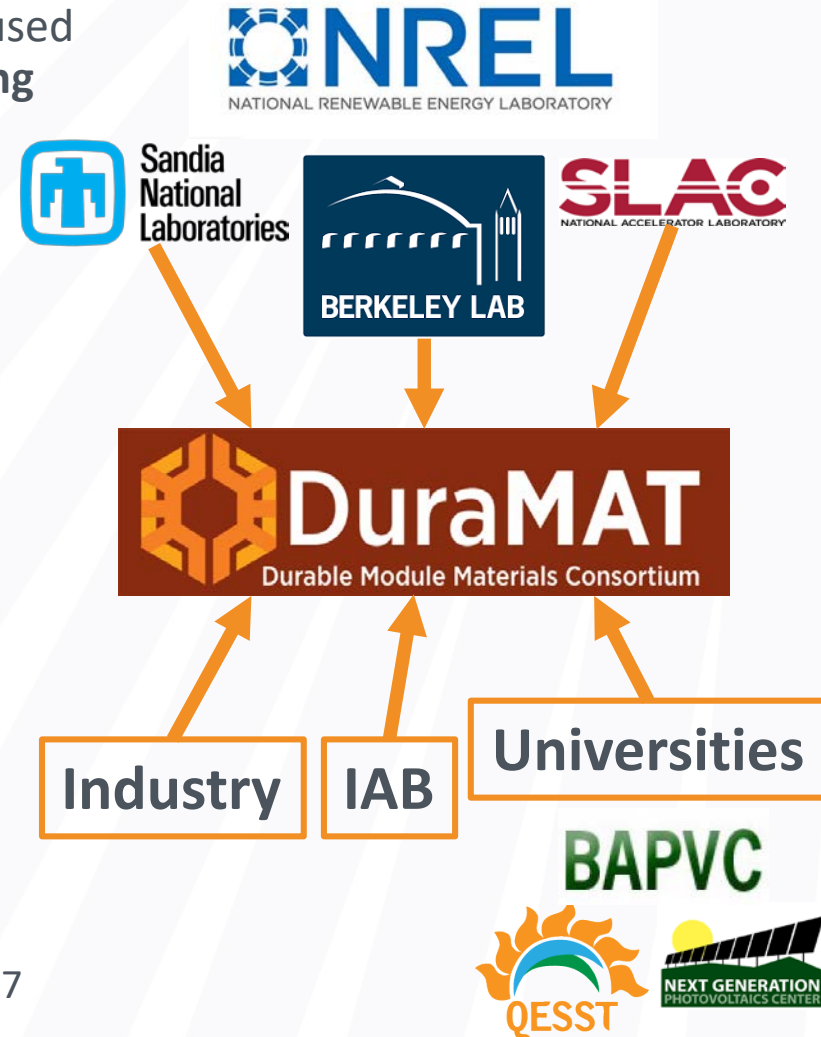
Reliability and Durability Research Challenges

Source: Kontges et al, IEA-PVPS, 2014
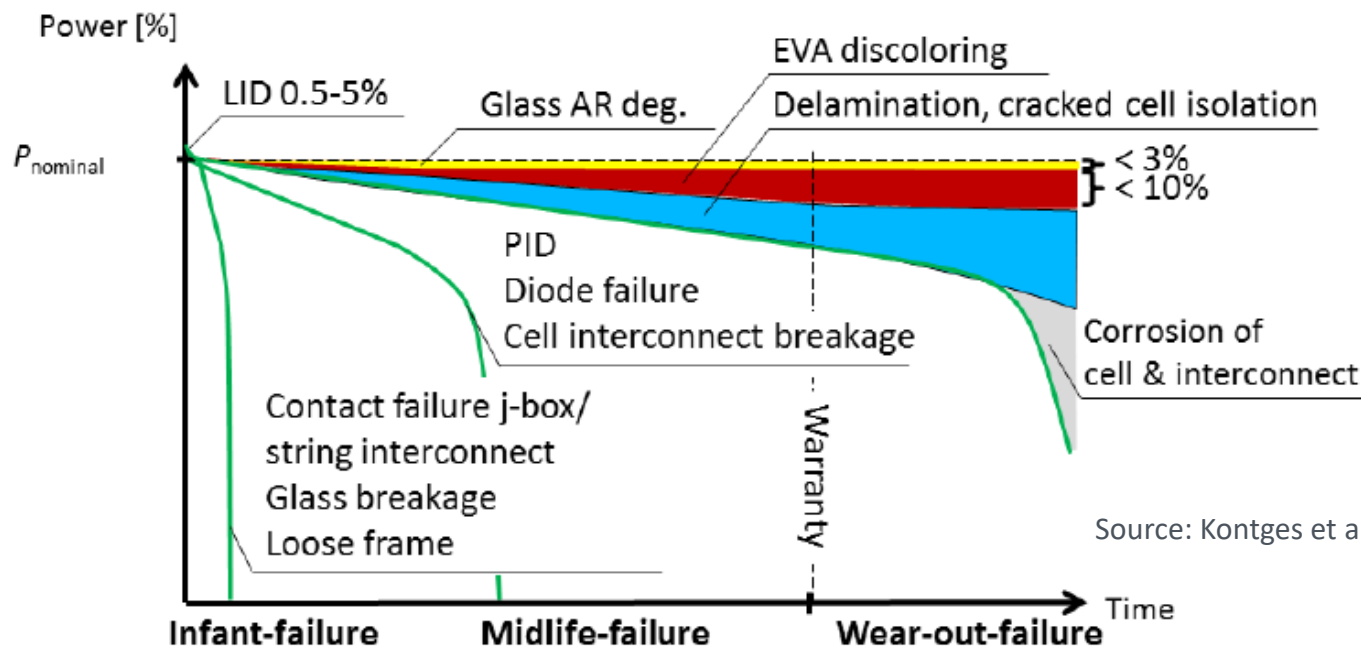
- Connect **specific bills of materials** and **climates** to degradation patterns?
- Can we connect **field performance** to **BOM** and **system** components?
- Develop more accurate and shortened **accelerated tests**?
- Can **physical models** describe the degradation mechanisms induced by accelerated tests and field exposure?

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DuraMAT Lab Capabilities

Data Mgmt. and Informatics Lead: Anubhav Jain, LBNL Infrastructure: Build data hub Demonstration Project: PVDAQ	**Predictive Simulation** Lead: Kevin Leung, Sandia Demonstration Project: Build full-size high aspect ratio module simulation toolset
Materials Forensics Lead: Mike Toney, SLAC Demonstration Project: Multi-functional anti-soiling/AR coating, backsheet degradation, encapsulant adhesion	**Module Prototype and Testing** Lead: Peter Hacke, NREL Demonstration Project: Combined Accelerated Stress Test of backsheets
Field Testing Lead: Bruce King, Sandia Demonstration Project: Development of non-destructive field test methods Infrastructure: Upgrade data transfer	**Technology to Market** Lead: Mike Woodhouse, NREL Infrastructure: Provide economic guidance impacts of capabilities and projects, critical industry issues
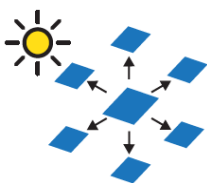
DuraMAT Data Hub – A path Toward Integration
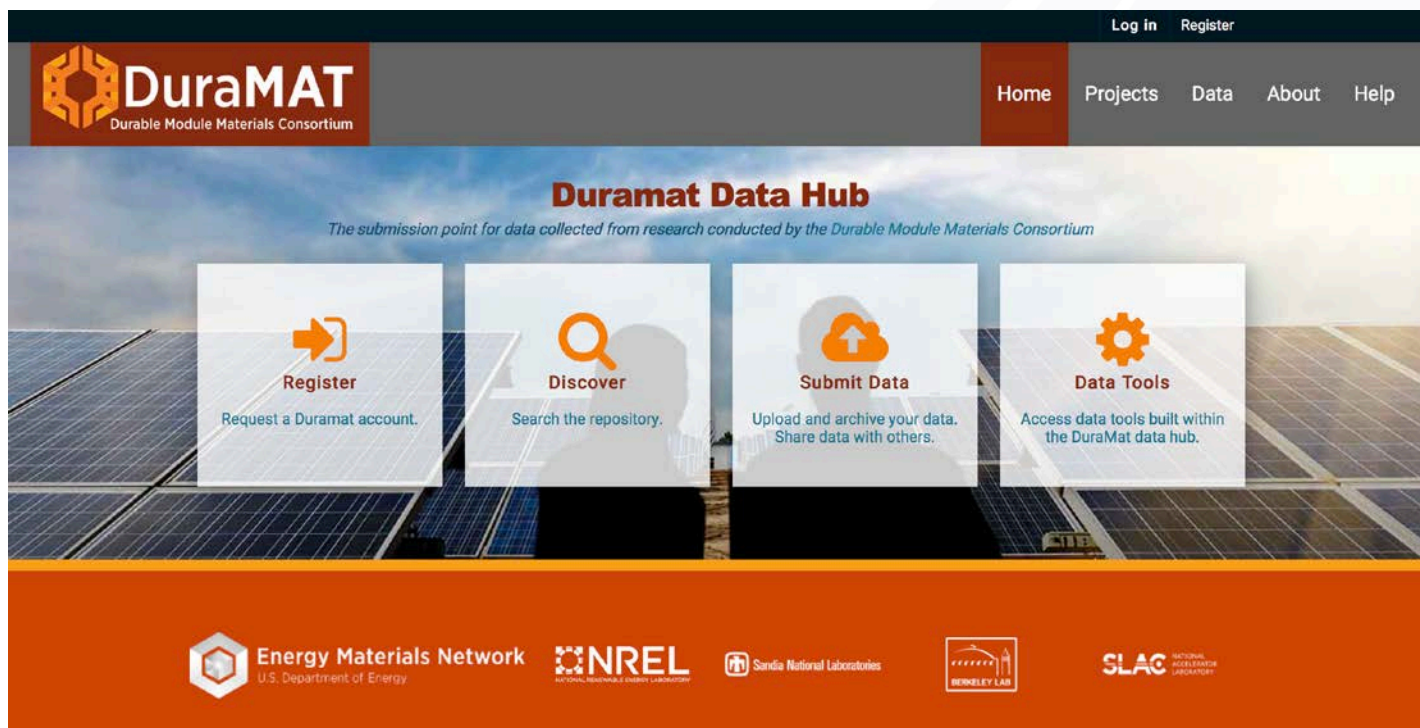
- C-KAN database platform and analysis tools up at:
  - https://datahub.duramat.org
- Anubhav Jain and Ben Ellis @LBNL, Robert White @NREL

DuraMAT Data Hub Vision

- Design, build, and deploy a secure data hub for highly heterogeneous data from many institutions that allows access and analysis to enable new discoveries

- Goals for Data Hub
    - Scalable custom data platform
    - Leverage "big" time-series data
    - Include BOM and system components
    - Standard data and metadata formats
    - Data visualization
    - Data security

- Next steps:
    - PVDAQ performance data
    - Building out analysis tools
        - Cloud based
    - Stakeholder feedback / input
    - Integration of PV Lifetime / RTC
    - Integration w/ PVLIB & RdTools

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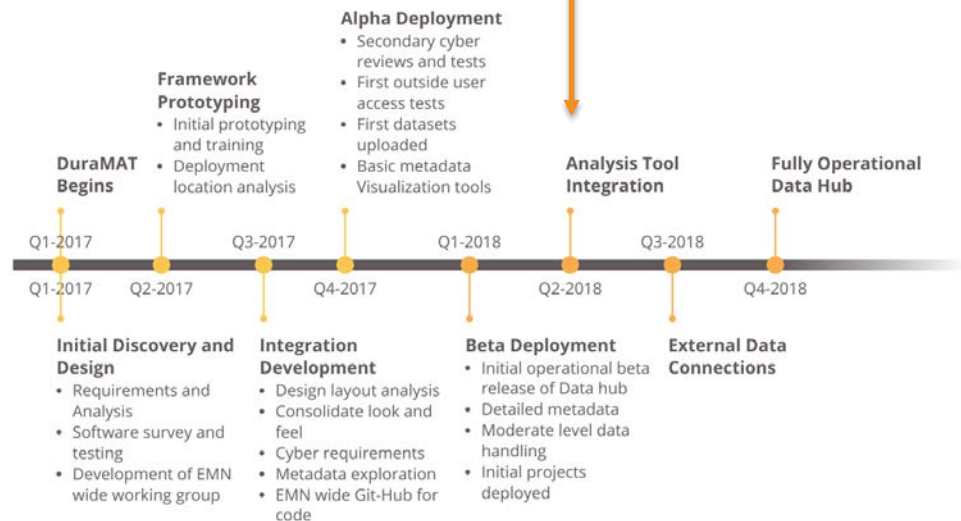
DuraMAT Datahub Dashboard: Initial Analysis Tools

Interactive map of tracked systems
- Zoomable
- Select sites for further analysis
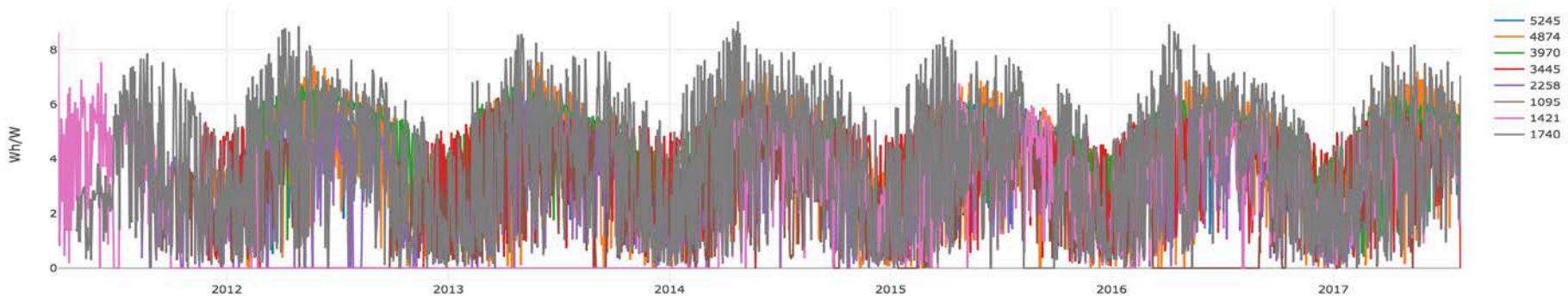
System metadta
- Filterable/searchable
  - Select sites for further analysis
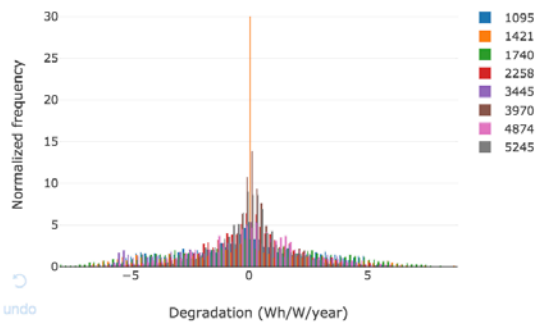
Time-Series System Performance Data

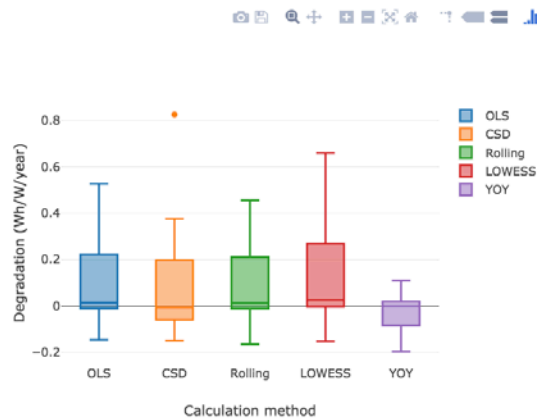Set data filters, smoothing strategies, and degradation rate calculation methods

Visualize raw system data

Planning to include more rate calculation methods and data cleaning methods from open-source tools (RdTools, PVLib, Pecos, etc)
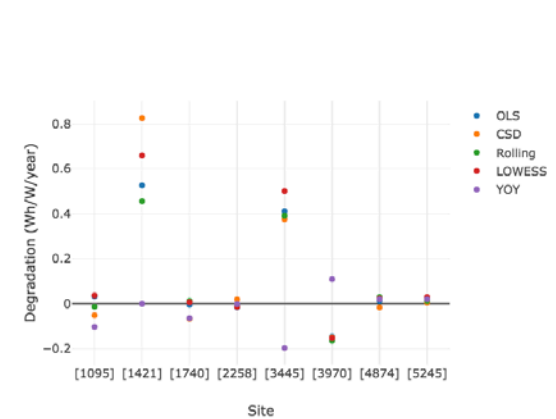
Summary statistics of degradation rate by method and by system

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IV Monitoring and Analytics Dashboard

IV Curve Analytics

Explore statistics of mismatching and PV parameters over time. Summary tab is only affected bywhich strings are chose. Scatter and density plots can be further explored by plotting parametersagainst one another. Set number which strings and axes to plot and press 'Run analysis' button.If any parameters are changed, you must press 'Run analysis' again to update the plots. Be patient ifyou have selected more than a few strings!

Select individual systems to investigate
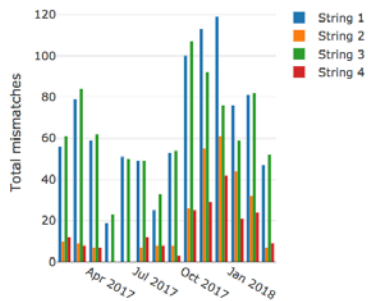
Select strings: × 1 × 2 × 3 × 4

X-axis values: Irrad
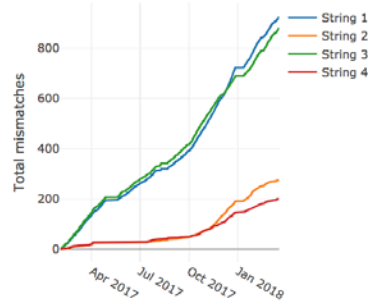
Y-axis values: Ff

Filter outliers (IQR): ○ True ● False

Set parameters: RUN ANALYSIS

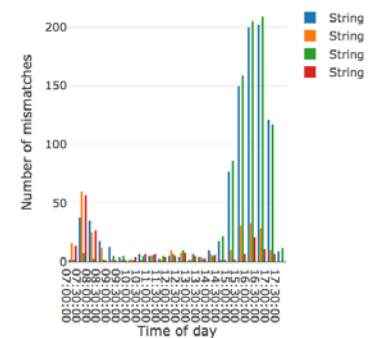| Summary	Scatter plots	Density plots

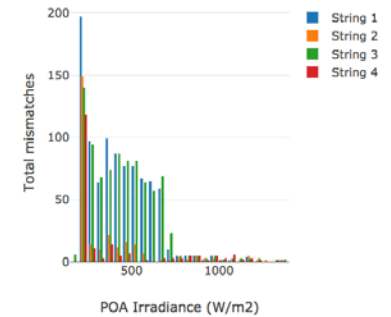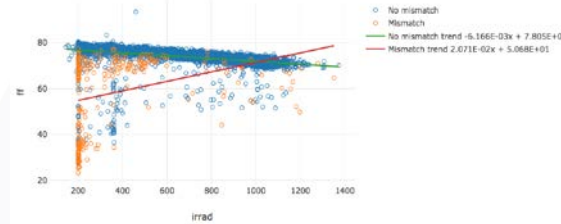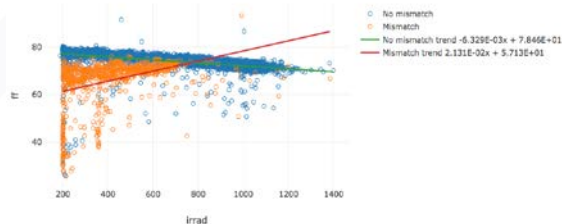Monitor mismatching events in string-level IV curves

Mismatches per month over system lifetime

Cumulative mismatches over system lifetime

Mismatching incidents by time of day

Mismatching incidents per irradiance

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Data Hub Opportunities

- **DuraMAT Data Hub**
  - What **dream dataset** would you like to see in the Data Hub?
  - What types of **analytic tools** would be most helpful?
  - What dataset related to module durability would you be **open to contributing to the Hub**?

- **Expanding DuraMAT Capabilities**
  - Are there capabilities from industry, universities, or national labs that **you could contribute to the DuraMAT network**?
  - What other **capabilities would you like to see**?

- **DuraMAT Research Funding**
  - Are there **R&D projects or tools** that you could propose to DuraMAT funding opportunities to work with the capability network?
  - Next industry and academic funding opportunity coming in soon
  - www.duramat.org

Toward an Integrated System Performance Platform

- DOE sees an opportunity to **leverage the DuraMAT Data Hub** as a resource to **integrate open tools and platforms**
  - Leverage activities across the program
  - Integrate performance data, system design, accelerated testing, and field testing
- Provide **web-based time-series performance database** and **toolset** to build an analysis platform for system performance and design
  - With opportunities for both **public (open)** and **proprietary data**
  - Analysis of large time-series performance datasets to **identify degradation mechanisms** and **establish degradation rates** for products and systems based on BOM and components
- **Hub** for **qualification** data and **performance** data to bridge the gap between the two sides of the PV industry
  - Link PV modules and systems due diligence to field performance
  - Enable improved system reliability and reduce risk and finance costs through open data formats, database, and tools

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DOE SETO 2018 Funding Opportunity Announcement

- SETO issued 2018 FOA for $105.5M in funding
  - Projects that address the affordability, flexibility, and performance of solar technologies on the grid
 - www.energy.gov/eere/solar/
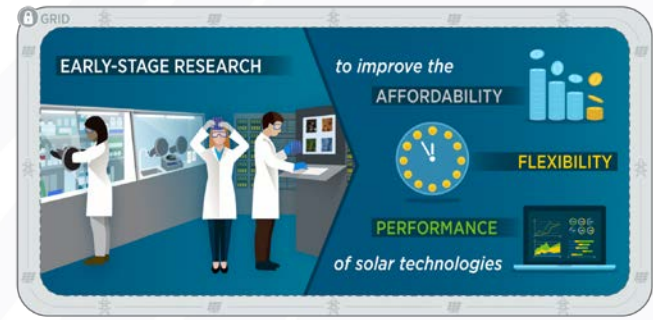
- Rapidly approaching due dates:

  - **Friday, May 4th**, 3PM Eastern –Letter of Intent
  - **Wednesday, May 9th**, 3PM Eastern – Concept Paper

  - June 26th, 3PM Eastern – Full and SIPS Applications due

  - Selection notifications expected in September

- ## FOA Topics
  - Topic 1: Advanced Solar Systems Integration Technologies
  - Topic 2: Concentrating Solar Power Research and Development
  - Topic 3: Photovoltaics Research and Development
  - Topic 4: Improving and Expanding the Solar Industry through Workforce Initiatives

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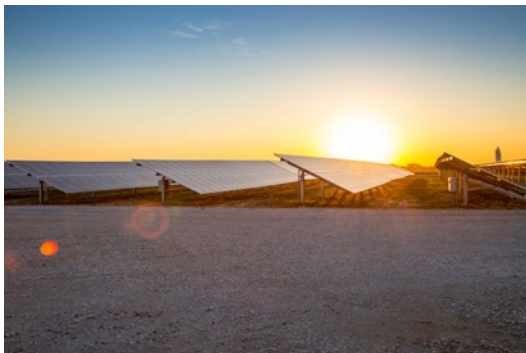
Thank You!

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