Break

We will reconvene at 1:00pm EST

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

2022 SETO PEER REVIEW

Subprogram Portfolio Overview

energy.gov/solar-office

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

2022 SETO PEER REVIEW

Systems Integration

Program Overview

January 31, 2022

energy.gov/solar-office

Guohui Yuan, Program Manager

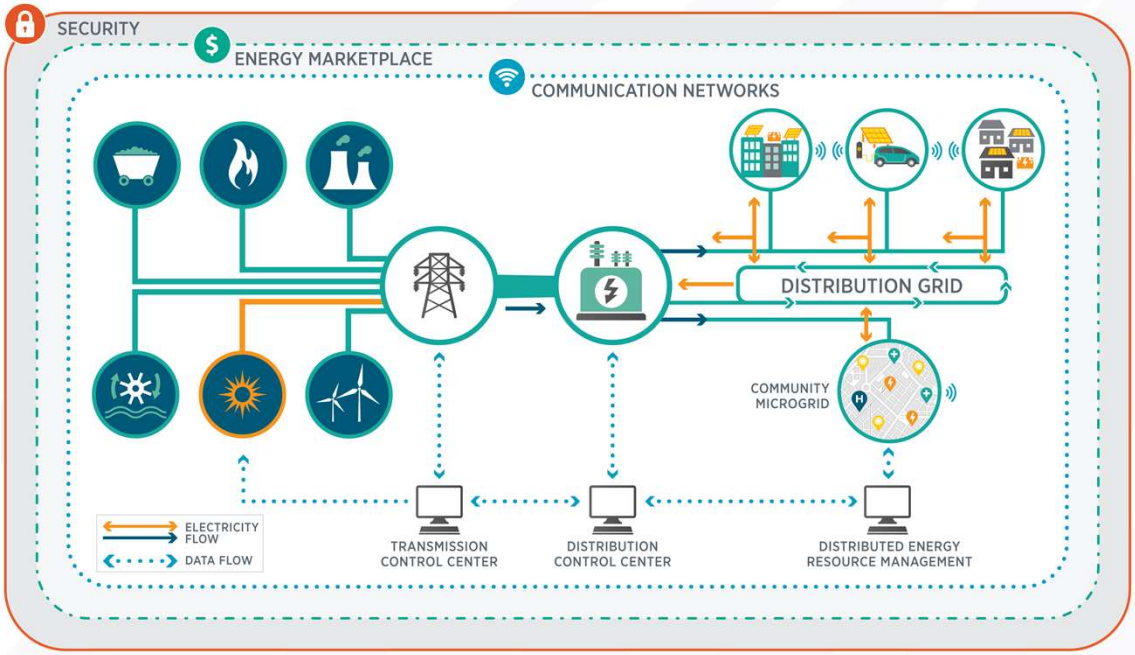
What is System Integration?



Next-Generation Inverters Enable Solar Energy Integration - YouTube

SETO Systems Integration (SI) Program

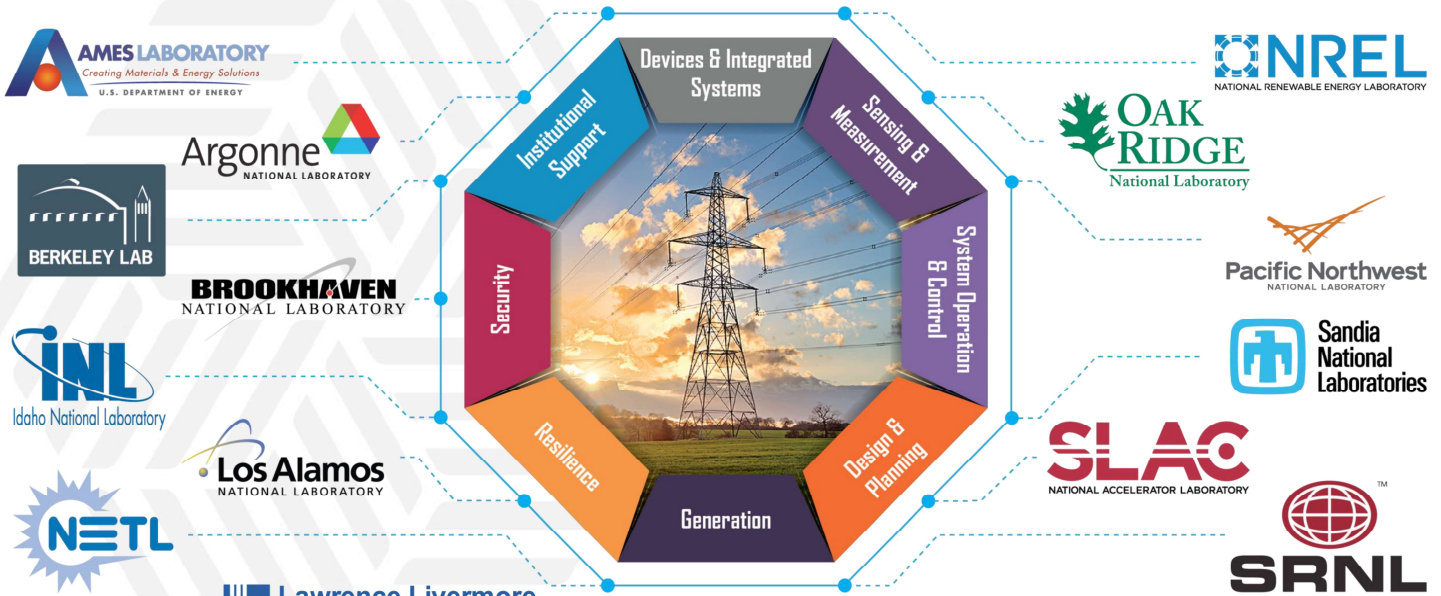
The Systems Integration (SI) subprogram supports **research, development, demonstration, and deployment** (RDD&D) of technologies and solutions – focusing on technical pillars **data, analytics, control, and hardware** - that advance the **reliable, resilient, secure and affordable** integration of solar energy onto the U.S. electric grid.



GMI – DOE-Wide Collaboration

DOE's Grid Modernization Laboratory Consortium – 14 National Labs – 100+ Partners

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy



January 28, 2020 | 1

Systems Integration Team


Guohui Yuan


Shay Banton


Bishnu Bhattarai


Kemal Çelik


Patricia Clark


Tiffany Jones


Rebecca Glaser


Rodney Kizito


Marissa Morales-Rodriguez


Robert Reedy


Yi Yang


Thomas Rueckert


John Seuss


David Walter

System Integration Key Research Areas

System Planning

- Develop methods and tools for short- and long-term power system planning with high solar contribution.
- Address issues in system reliability, resource adequacy, generation variability, system flexibility.
- Include power system modeling, solar and load forecasting, and interconnection standards.

System Operation

- Develop real time situation awareness and control solutions for high-level solar integration
- Address operation issues for both bulk power and distribution systems
- Include operation data integration, grid services, system stability and protection, power flow analysis, and control optimization.

PV for Resilience & Cybersecurity

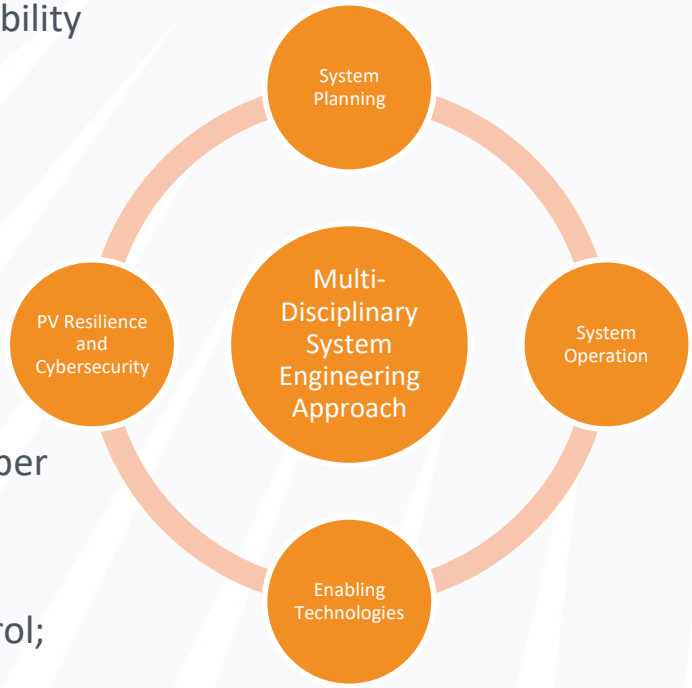
- Develop solutions to ensure the continuity of electric power service and faster recovery during grid disruptions.
- Address physical weather-related hazards as well as cybersecurity threats
- Include integrated solutions with solar PV, energy storage, and other DER.

Power Electronics & Enabling Technologies

- Develop new foundational hardware, software, and system technologies to enable solar grid integration.
- Include power electronics, AI/ML and data analytics, sensing and communications, computing, and advanced testbeds.

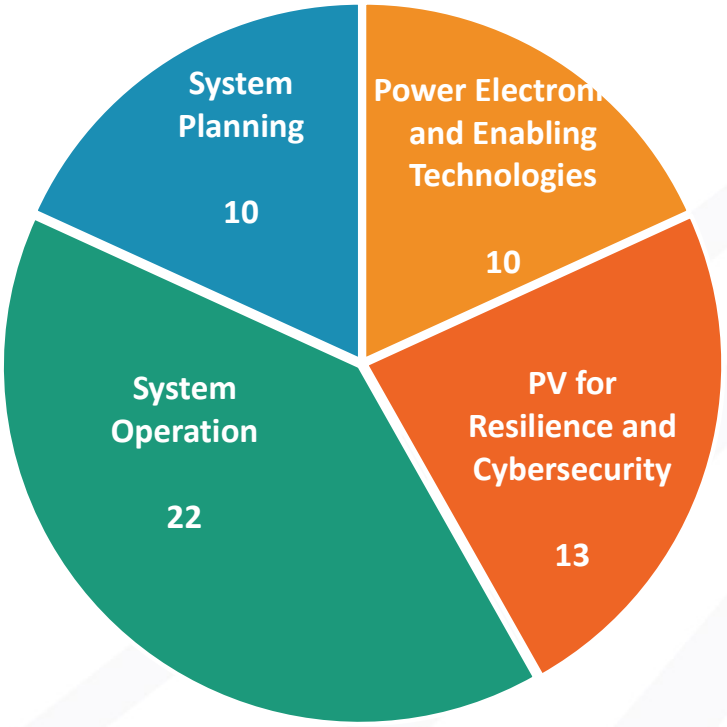
Research Programs

- FY22 SETO Lab Call – transient/dynamic modeling, open data, NSRDB, reliability and cybersecurity standards
- FY21 SI & Incubator FOA – grid-forming consortium, BTM solar integration
- FY20 SETO FOA – resilient community microgrids, cybersecurity, hybrid PV plants
- FY19 SETO Lab Call – all SI topics
- FY19 GMLC Lab Call - resilience models, sensing and measurement, cyber security
- FY19 SETO FOA - grid services, system protection, grid-forming inverter, cyber security
- ASSIST FOA – situation awareness, and resilience for critical infrastructures
- Advanced Power Electronics FOA - Improving PE efficiency, reliability, control; WBG devices
- GMLC-RDS Lab Call - Resilient distribution system design, demonstration, and value analysis

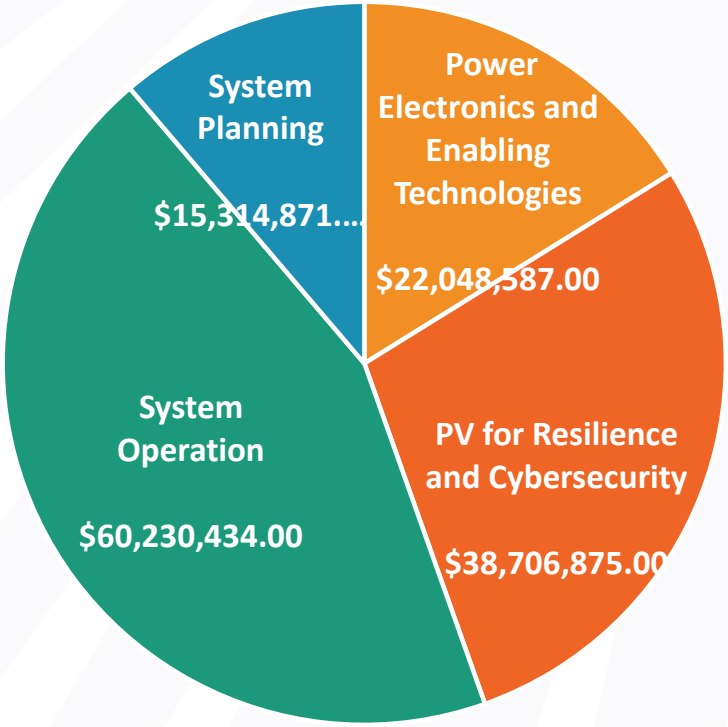


Systems Integration (SI) Peer Review Portfolio

SI Projects by Topic Area



SI Funding by Topic Area



Justice, Equity, Diversity & Inclusion (JEDI)

JEDI Strategy for SI:

- Diversify Merit Reviewer pool
- Diversify selection of Awardees
- Include DEI requirements in program designs
- Enhance community resilience through Technology demonstrations

Recent JEDI Successes for SI:

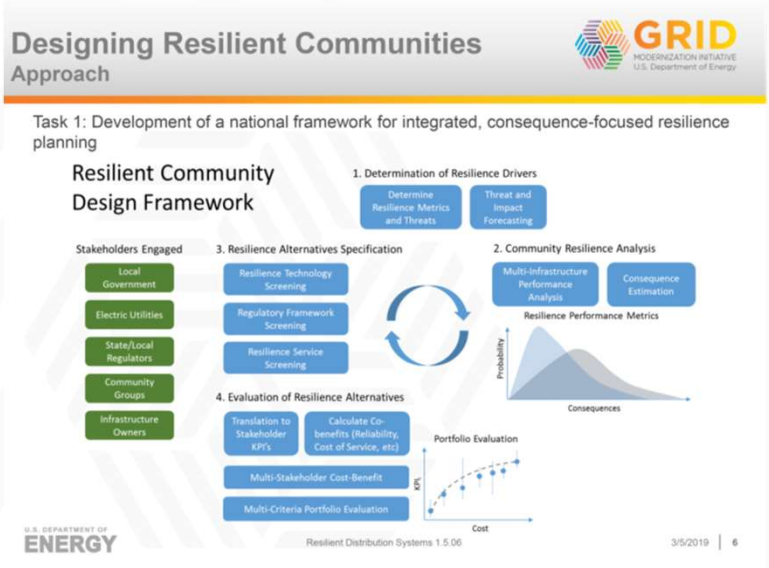
- Bronzeville, Chicago microgrid project successfully completed final testing (January 2022)
- Diversity of SI subprogram team
- 14 applications for SI focus area of MSI STEM Research and Development Consortium (MSRDC)



7.7 MW community microgrid that will provide service to approximately 770 customers in the historically Black neighborhood of Bronzeville, Chicago. Photo courtesy of ComEd

Stakeholder Engagement

- Program-level
  - Actively listening
  - Stakeholder workshops and webinars
  - Technical workshops
- Project-level
  - Include TRCs, IABs, SAGs, surveys to solicit diverse stakeholder voices to guide research
  - Build in stakeholder engagement tasks and milestones.
  - Transparency in research methodologies
  - Disseminate results in public reports, online content, training webinars, and demonstrations



Source: Bobby Jeffers & Robert Broderick)



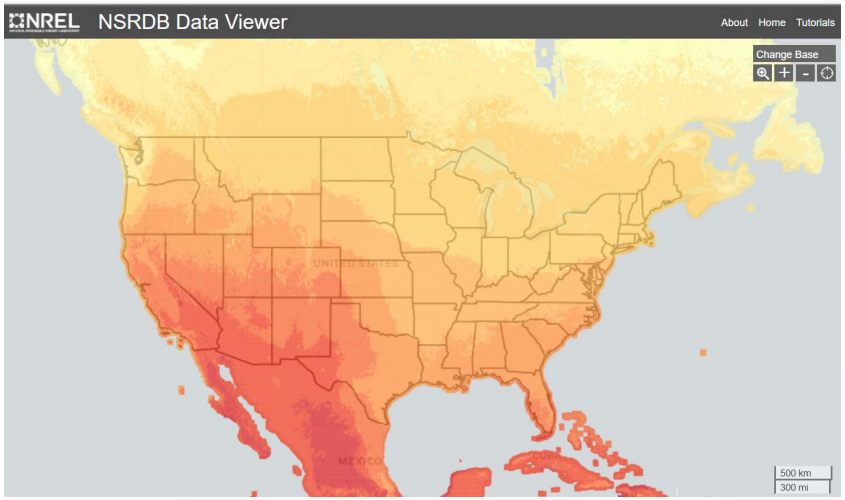
DOE-led Stakeholder meeting in Puerto Rico

Challenges

Solar Generation Variability and Uncertainty

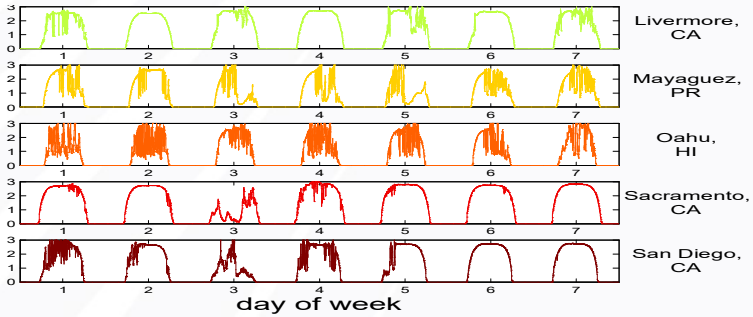
Solar Irradiance Data (GHI, DNI):

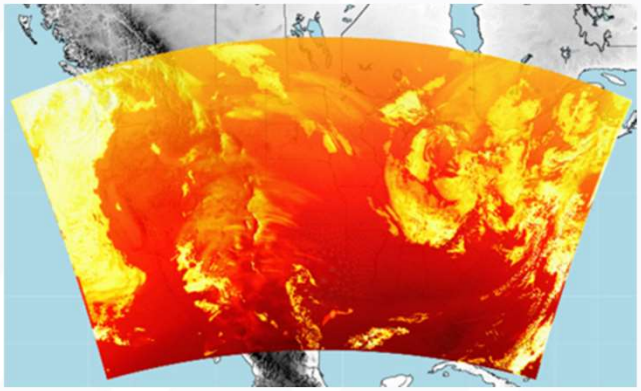
- Historical = NSRDB
- Real time = satellites and ground sensors
- Future = forecast



2019 Annual Mean of GHI from NSRDB (2km x 2km, 5 min, Terabytes) Home - NSRDB (nrel.gov)

Sample measurements (1 min)

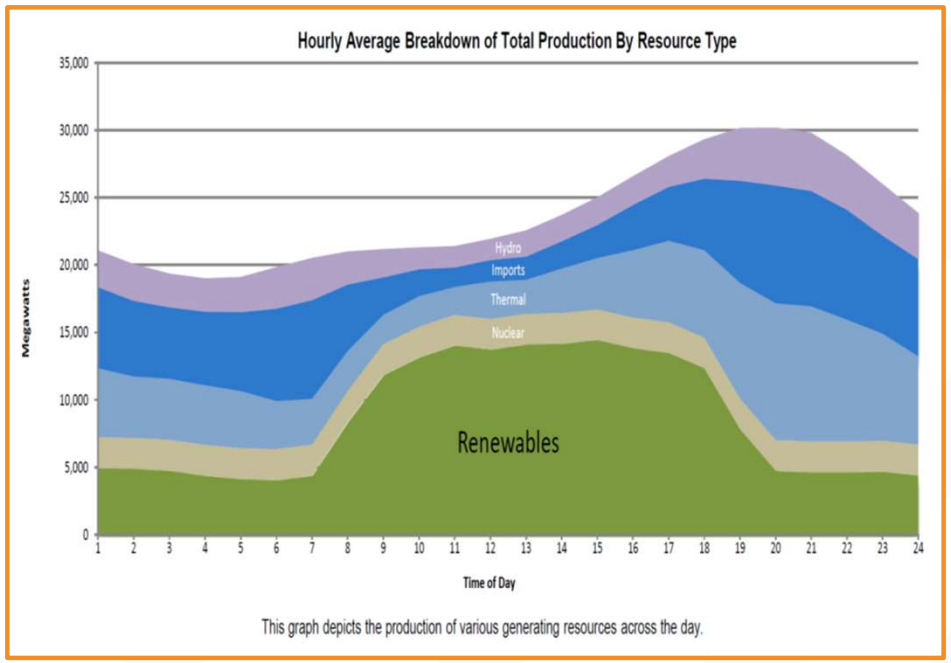


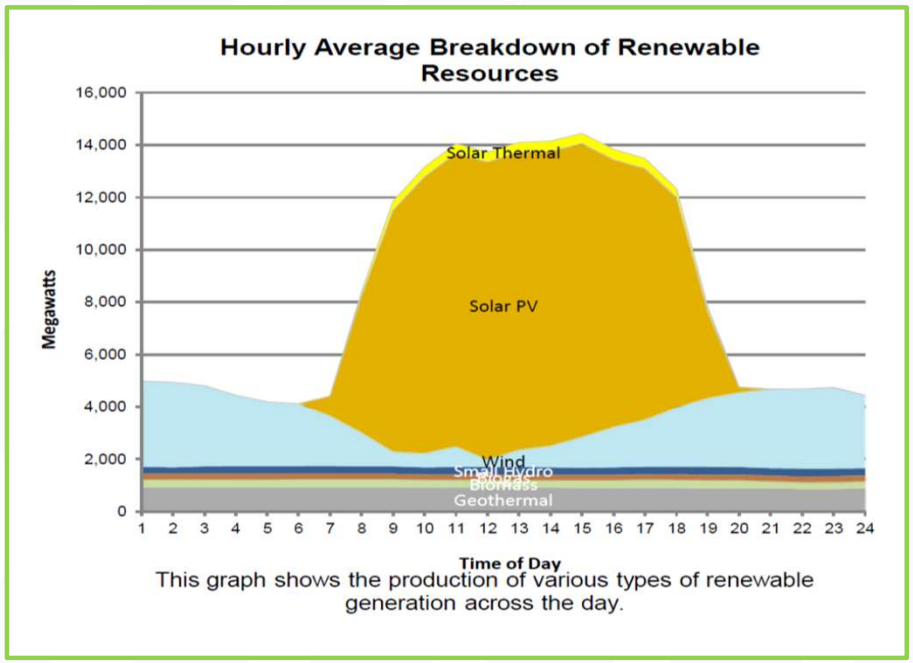


WRF-Solar® | NCAR Research Applications Laboratory | RAL (ucar.edu) ***Run on HPC***

Operating a Decarbonized Electricity Grid

- *Daily renewable profile (CAISO, April 24, 2021)*
- ***Served 94.5% of the load served by RE at 2:28pm for 4 seconds***

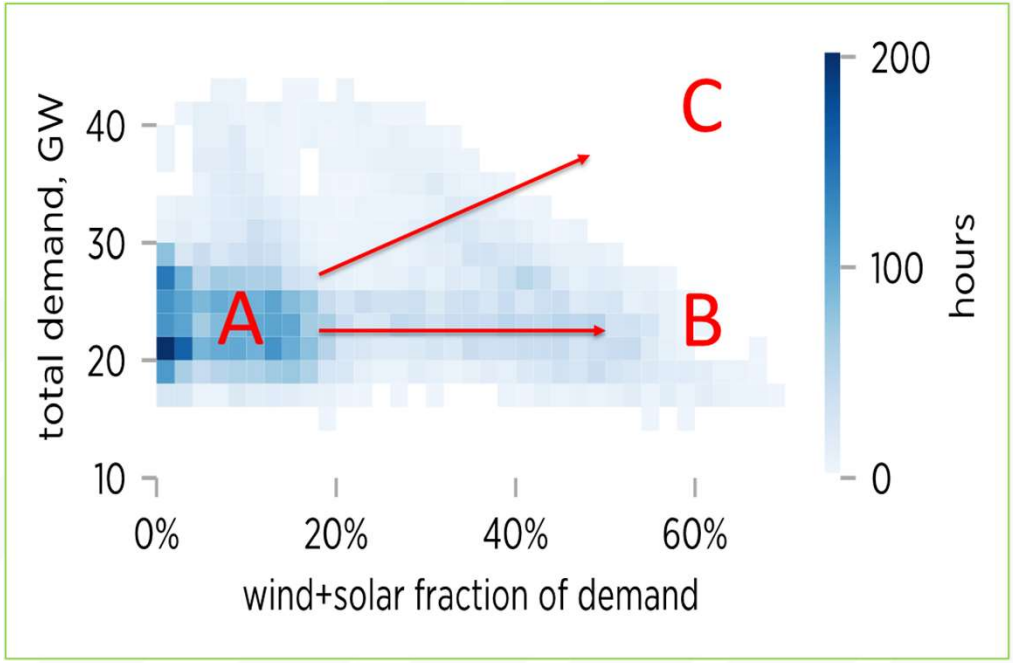




Operating a Decarbonized Electricity Grid (continue)

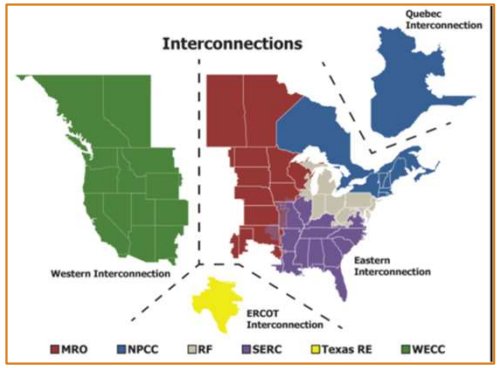
Power system	System size	Peak solar + wind *power* contribution	Annual solar + wind *energy* contribution
U.S. WECC	163 GW	36%	13%
U.S. ERCOT	80 GW	58%	20%
U.S. SPP	51 GW	69%	28%
U.S. CAISO[4]	44 GW	70%	20%
Australia NEM	35 GW	50%	21%
Ireland	7 GW	84%	36%
Oahu	4 GW	58%	22%
Maui	0.5 GW	80%	37%

[Solar Energy Technologies Office Multi-Year Program Plan | Department of Energy]

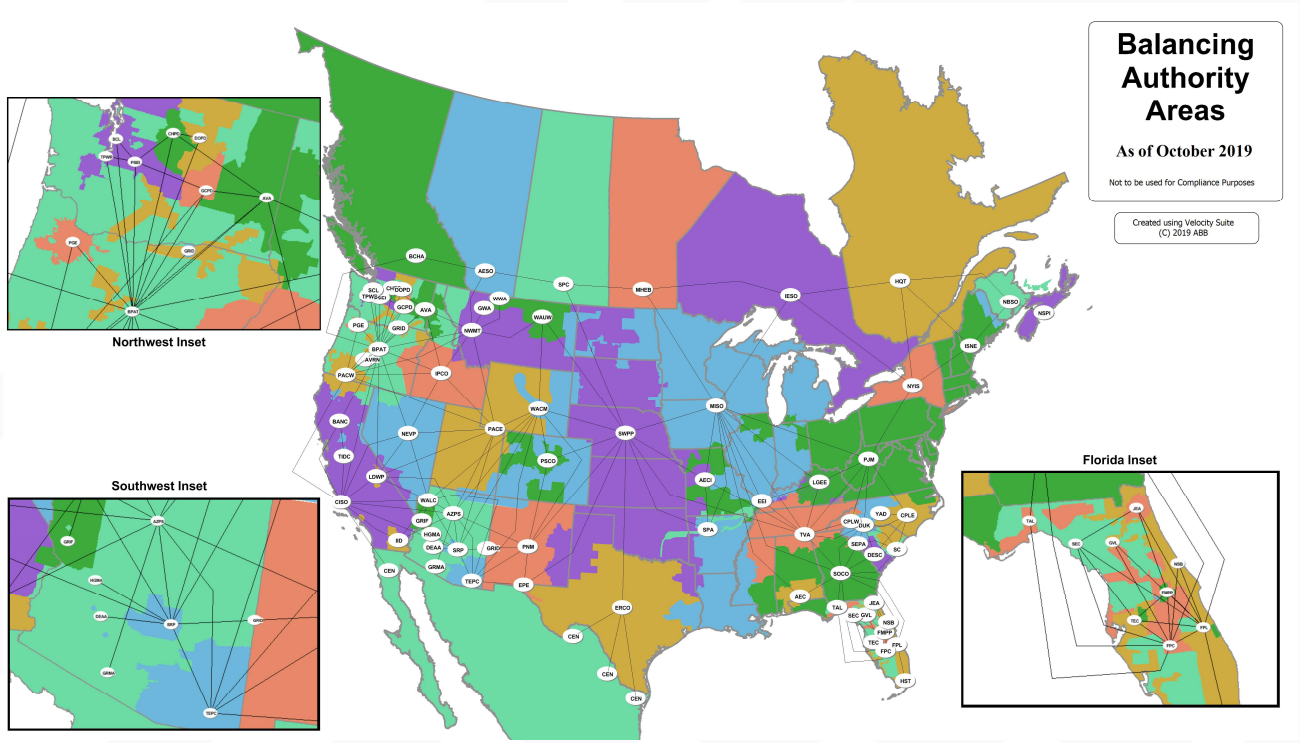


The frequency of occurrence of solar and wind power contributions at different demand levels in CAISO for 2019. For a vast majority of the operation periods, solar and wind penetration is low (Area A). Occasionally solar and wind provide a higher contribution to the generation supply but only at lower demand levels. (Area B). In the future, as solar and wind reach much higher deployment, the system will operate at high demand most of the times (Area C).

Scalability of Solar Integration on U.S. Electric Grid



Source: NERC



Natural Disasters and Cybersecurity Threats





Grid Stability and Resilience

Major Events

- May 2021, Odessa disturbance
  - Transmission fault
  - ERCOT solar output drops from 4.5GW to 3.5 GW in <1 min
- February 2021, TX winter storm power outage
- August 2020, CA rolling blackout
- 8/09/2019, UK blackout
  - lightening strike, 45 minute outage for 1.1 million customers
  - 737MW offshore windfarm output reduction
  - 150MW of small embedded generation disconnected; further 350MW of embedded generation disconnected
- 10/09/2017, Southern CA Canyon 2 Fire
  - transmission fault
  - 900 MW of solar PV resources lost; PV inverters trip off due to momentary cessation in response to voltage transients
- 9/28/2016, South Australian blackout
  - Extreme weather (high wind, high temperature)
  - 456 MW wind generation reduction
  - 850,000 customers lost power for hours
- 8/16/2016, Southern CA Blue Cut fire
  - transmission fault
  - 1200 MW of solar PV resources lost; PV inverters trip off due to frequency during transients



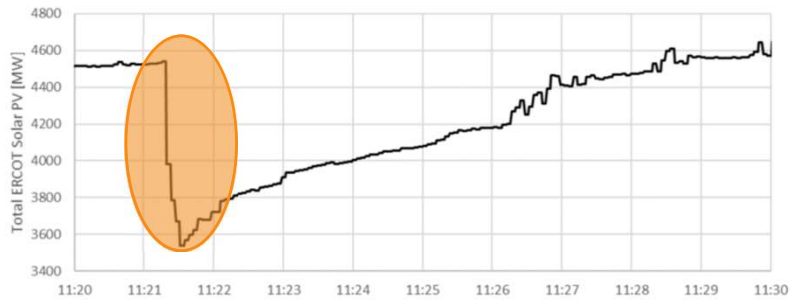
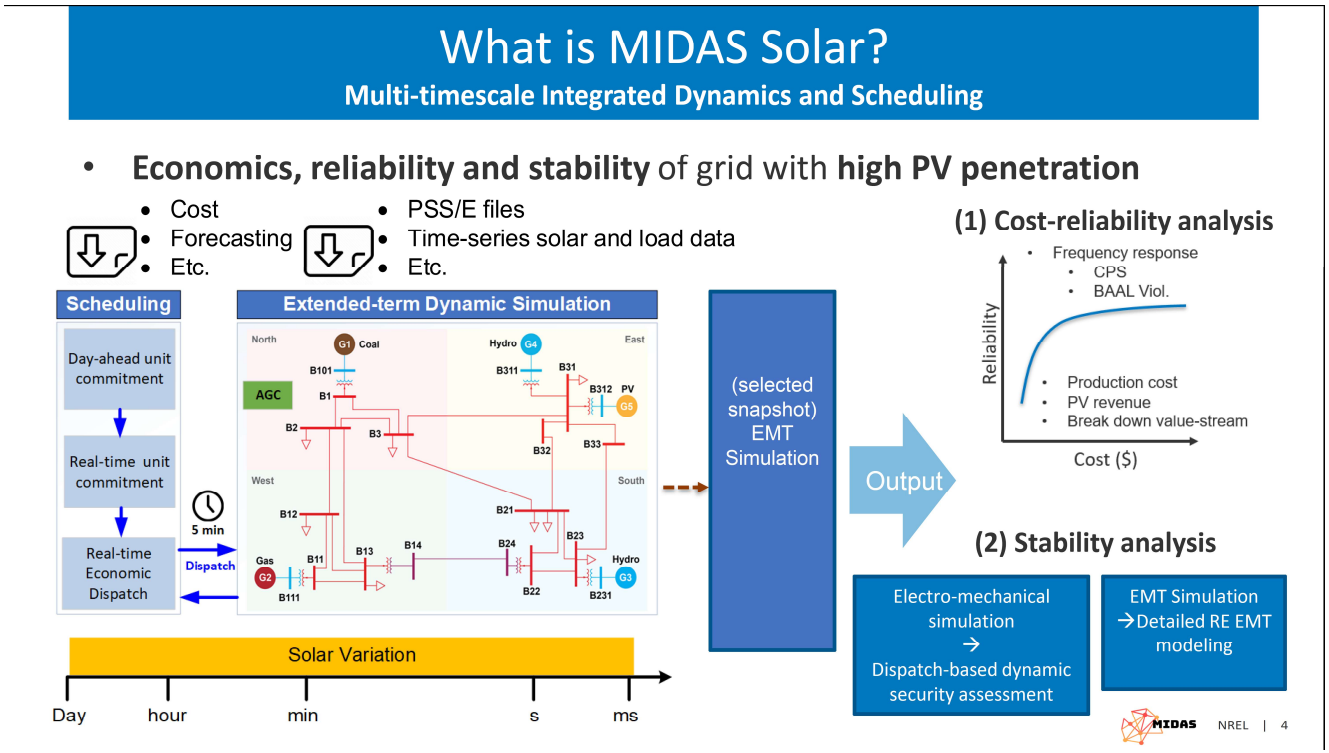


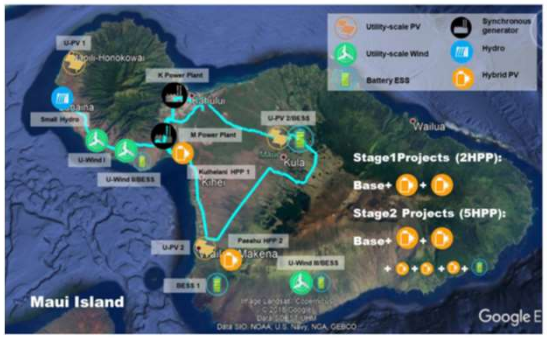
Figure I.5: ERCOT BPS-Connected Solar PV during Disturbance [Source: ERCOT]

System Planning

Modeling 100% Renewable Grid



Maui Grid

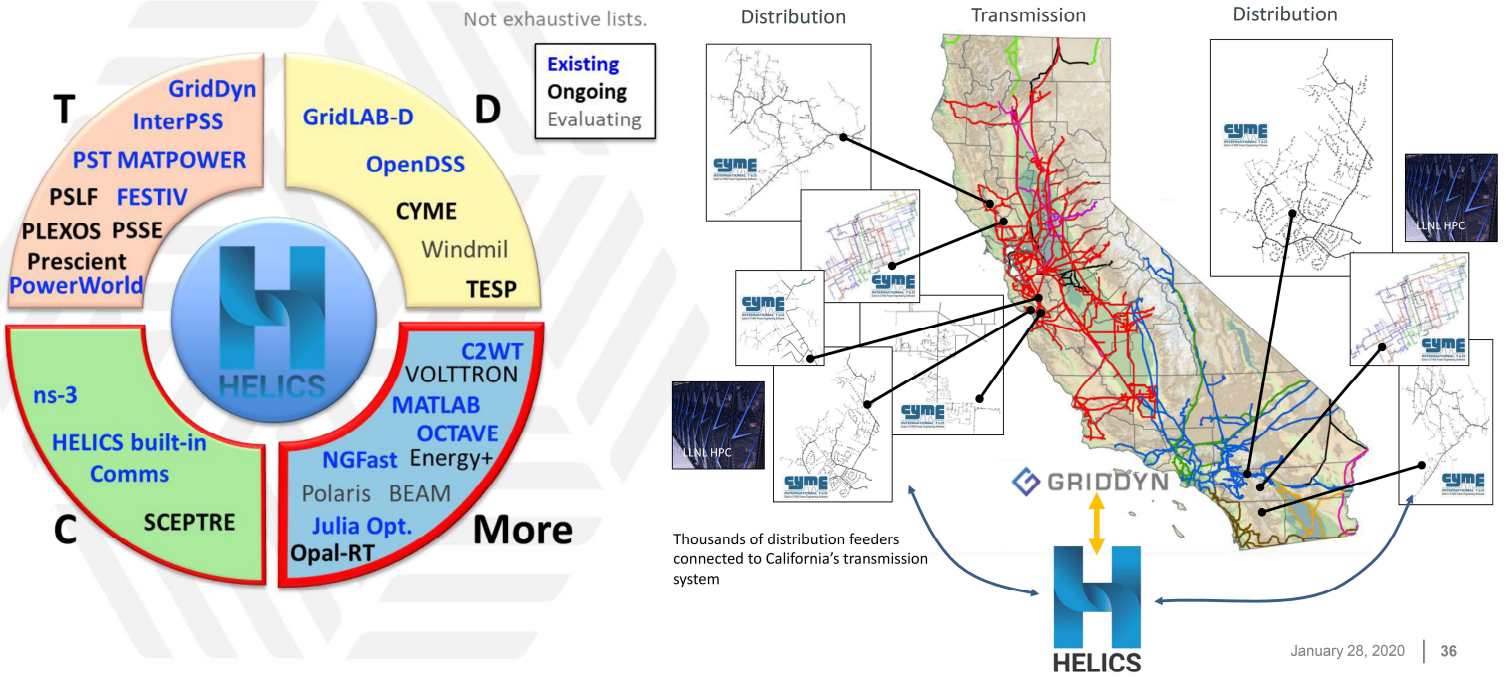


(Source: Jin Tan, NREL)

Multi-Domain Co-Simulation Platform

HELICS middleware enables coupling of transmission, distribution, communications and other models

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SOLAR ENERGY TECHNOLOGIES OFFICE

Develop and Validate 2032 WECC-ADS Solar Datasets

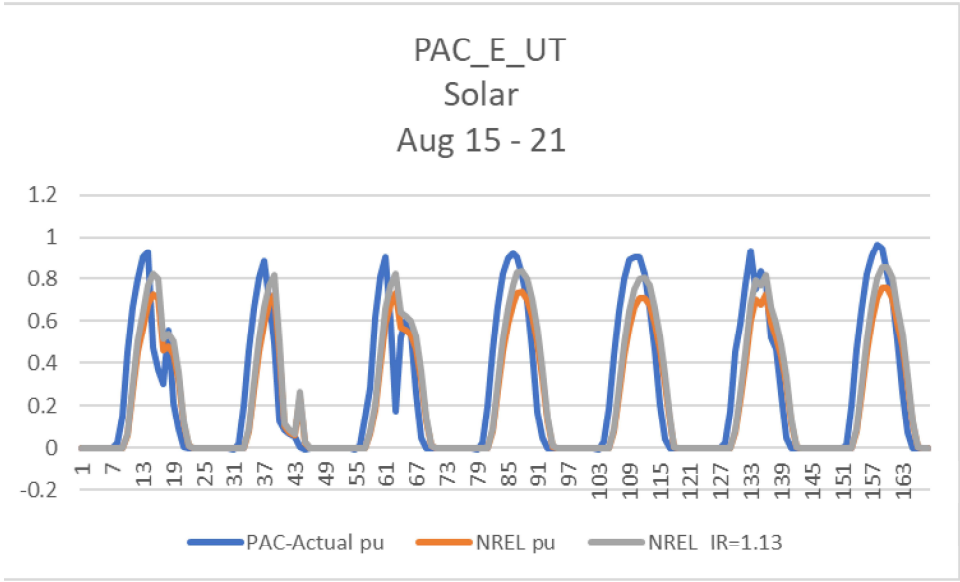
- Use existing NREL models and historic wind/solar data to create utility-scale and BTM solar datasets for the entire WECC region
- Validate with actual plant-specific data
- Support long-term system planning and wind/solar development
- Close collaboration between DOE, NREL, PNNL, and WECC staff

WECC

Anchor Data Set (ADS) 2032
Wind and Solar Data Validation

January 4, 2022

Jamie Austin, Chair



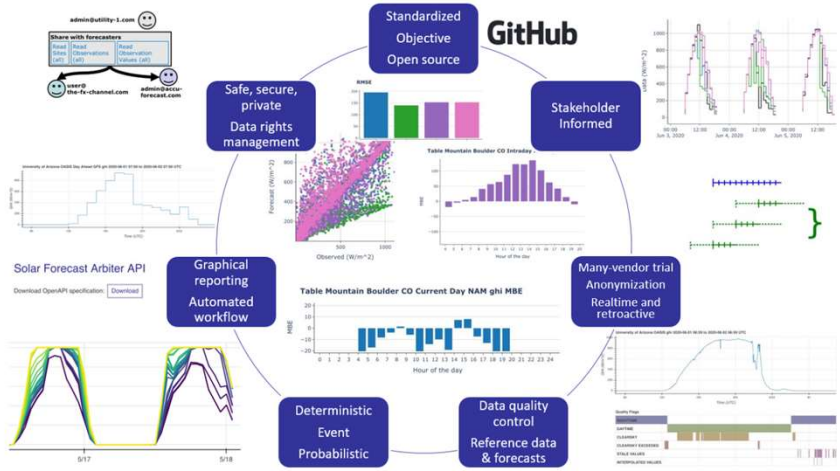
Unlocking the Value of Solar Forecasting

- Solar Forecasting Prize
  - Bringing together forecast providers a



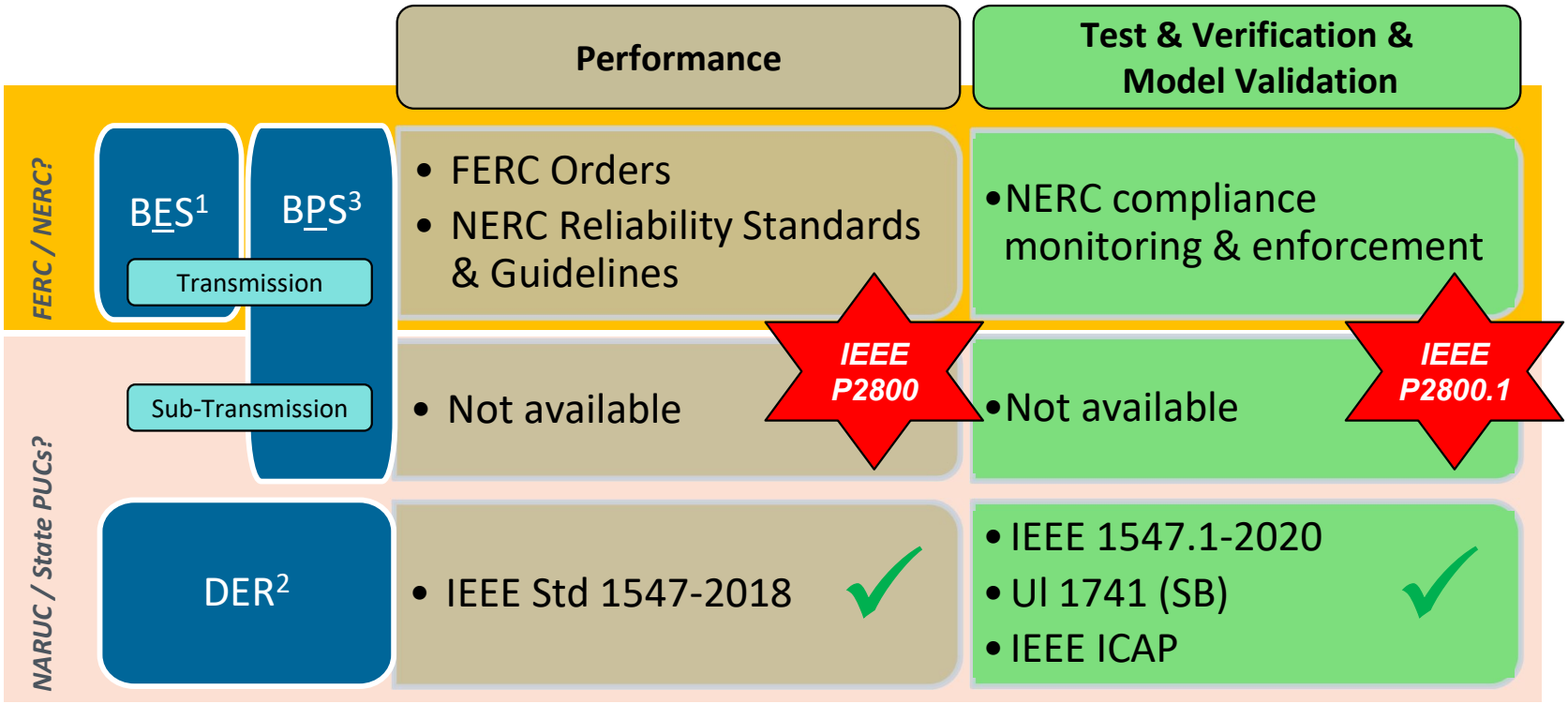
Solar Forecast Arbiter

A paradigm shift in forecast evaluation



(Source: University of Arizona)

Interconnection Standards Development



[1] NERC definition of Bulk Electric System: ≥100 kV with gross individual / aggregate nameplate rating greater than 20 MVA / 75 MVA

[2] DER connected at typical (radial) primary and secondary voltage levels

[3] transmission and meshed sub-transmission

IEEE standards are voluntary industry standards and must be adopted by the appropriate authority to become mandatory (e.g., Transmission Owners, NERC, FERC).

(Source: IEEE P2800 WG, Jens C. Boemer, et al)

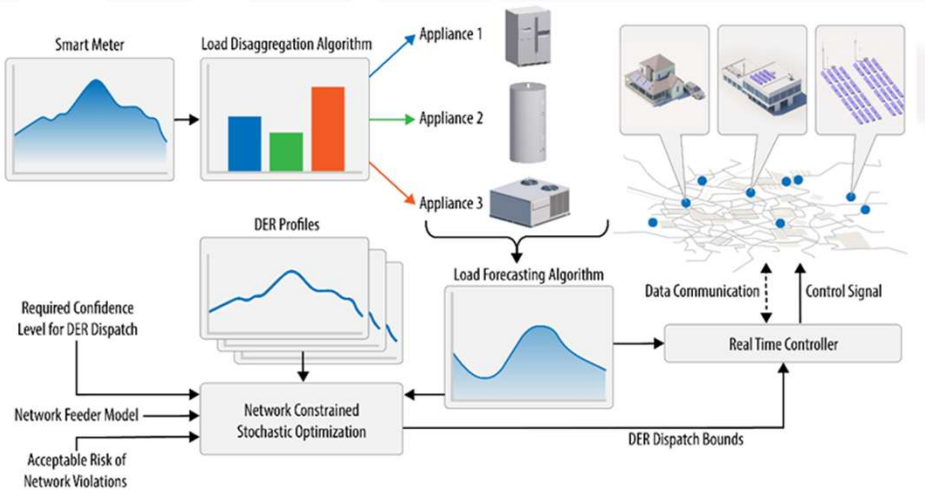
System Operation

Control of behind-the-meter DERs with AMI Data Integration

Project Description

- **Goal:** Develop and field-validate a control technology to enable optimal provision of grid services from BTM solar PV and other DERs.
- **Innovation:** 1) Smart meter as a controller with improved controllability and observability of BTM DERs for utilities. 2) Hierarchical control architecture with careful consideration towards data communication and computational complexity tradeoffs.
- **Approach:** 1) Leverage ground truth whole house consumption data to develop and validate load disaggregation and control algorithms. 2) Parallel hardware development. 3) integration, lab validation, field demonstration.

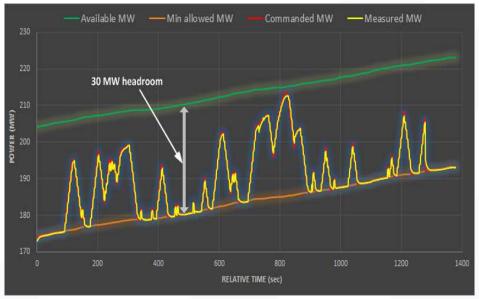
Solution Architecture (Eaton)

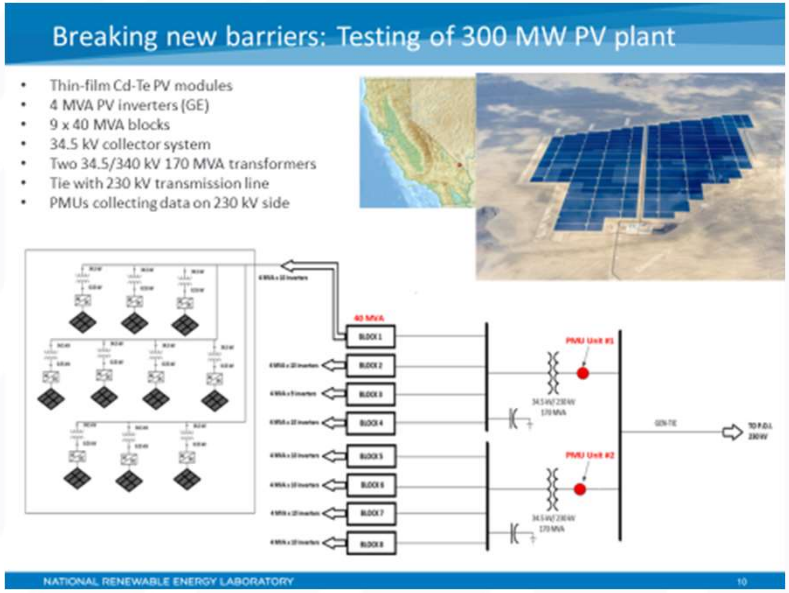


Demonstration of Essential Reliability Services from Solar PV

- NREL/CAISO/First Solar partnering in the 300-MW PV System Commissioning Test
- Winner of NARUC Innovation Award in 2017

- 4-sec AGC signal provided to PPC
- 30 MW headroom
- Tests were conducted for 30 minutes at:
  - Sunrise
  - Middle of the day
  - Sunset
- 1-sec data collected by plant PPC





Courtesy: NREL, Vahan Gevorgian
http://www.nrel.gov/docs/fy17osti/67799.pdf

"These data showed how the development of advanced power controls can enable PV to become a provider of a wide range of grid services, including spinning reserves, load following, voltage support, ramping, frequency response, variability smoothing, and frequency regulation to power quality."

UNIFI Grid-Forming Technology Consortium

NREL-Led, 5-Year, $25M Program

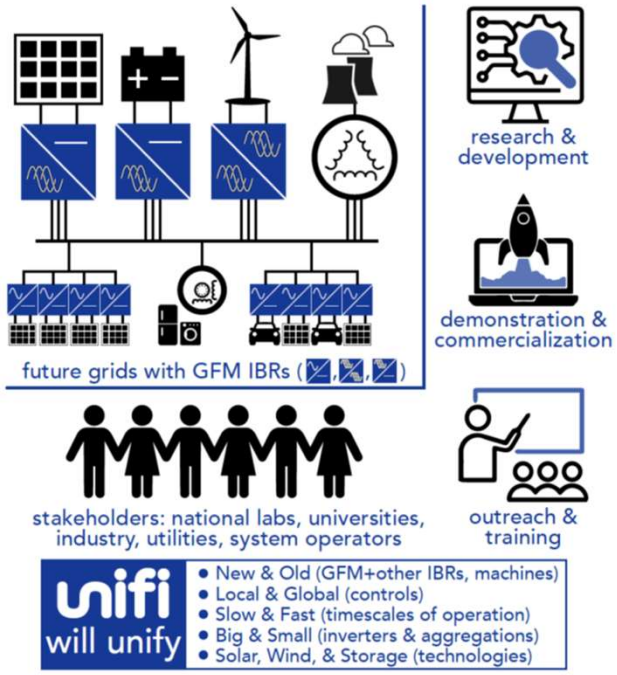


Figure 1: Mission, Vision, Goals, and Thrusts of UNIFI.

National Labs ☐ Project Co-leads, ● Project Team

- *National Renewable Energy Laboratory (NREL)* — B. Mather, Y. Lin, A. Hoke, G.-S. Seo, J. Wang
- *Pacific Northwest National Laboratory (PNNL)* — W. Du, T. McDermott, Q. Huang, M. A. Elizondo
- *Sandia National Laboratories (Sandia)* — A. Ellis, J. Flicker, M. Reno, B. Pierre
- *Lawrence Berkeley National Laboratory (LBNL)* — C. Roberts, J. Eto

Universities

- *University of Washington (UW)* — B. Johnson
- *University of Minnesota (UMN)* — S. Dhople
- *Georgia Tech (GT)* — D. Divan
- *Arizona State University (ASU)* — V. Vittal, R. Ayyanar
- *North Carolina State University (NCSU)* — I. Husain, S. Lukic, D. Lubkeman
- *University of Alaska Fairbanks (UAF)* — M. Shirazi
- *University of California Berkeley (UC Berkeley)* — D. Callaway
- *Temple University* — X. Lu
- *University of Illinois at Urbana-Champaign (UIUC)* — A. Domínguez-García, O. Ajala
- *University of Puerto Rico, Mayagüez (UPRM)* — E. I. O. Rivera
- *University of Wisconsin-Madison (UW-Madison)* — D. Gross
- *Virginia Tech (VT)* — A. Mehrizi-Sani

Inverter Manufacturers

- *General Electric (GE)* — R. Legg, S. Achilles, P. Arsuaga, R. Dutta, M. Bowman
- *Enphase Energy (Enphase)* — D. Zimmanck, P. Chapman
- *Siemens Corporate Technology (Siemens)* — U. Muenz
- *Hitachi ABB Power Grids (HAPG)* — D. Das
- *Danfoss* — D. Isaksson, M. A. Awal, L. D. Flora
- *Eaton* — A. Rockhill

Industry Labs, Utilities, & System Operators

- *Electric Power Research Institute (EPRI)* — A. Tuohy, D. Ramasubramanian, E. Farantatos, A. Huque, B. Seal, W. Wenzong, J. Boemer
- *Hawaiian Electric Company (HECO)* — C. Ching, D. Ishimura
- *Southern California Edison (SCE)* — J. Castaneda
- *Pacific Gas & Electric Company (PG&E)* — S. Xu
- *Portland General Electric (PGE)* — L. Bekkedahl
- *New York Power Authority (NYPA)* — G. Stefopoulos
- *Commonwealth Edison (ComEd)* — A. Vukojevic
- *Southern Company* — C. R. Black
- *PacifiCorp* — S. Wang
- *ISO New England (ISO-NE)* — X. Luo
- *Midcontinent ISO (MISO)* — J. Harrison

Real-time Simulation & Software Vendors

- *Typhoon* — I. Celanovic
- *OPAL-RT* — S. Chakraborty
- *Electranix* — A. Isaacs

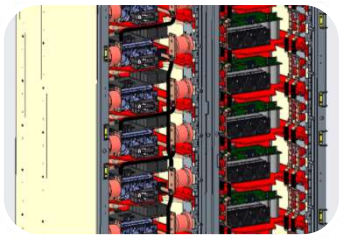
Additional Industry Partners

SEL, Manitoba Hydro International, plexim, terabase, California ISO, NRECA, Rte, TMEIC, SPP Southwest Power Pool, CenterPoint Energy, Global PST Consortium, FREEDM Systems Center, Carrier, Power America, Xcel Energy, PGS Tech, DERlab, Schneider Electric, SMA, WECC, Powertech, PSERC, Fraunhofer, PowerWorld Corporation, ercot, Kaua'i Island Utility Cooperative, Beckwith Electric Co., Inc.

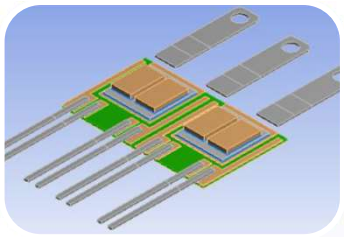
This document contains confidential, proprietary, or privileged information exempt from public disclosure.

Power Electronics

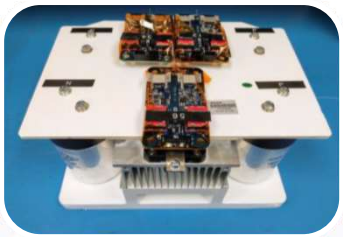
Power Electronic Hardware Technologies



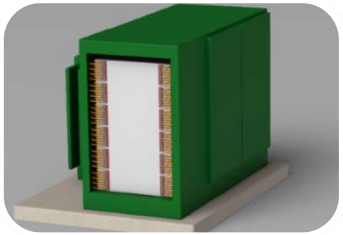
MV SiC PV inverter (UT Austin)



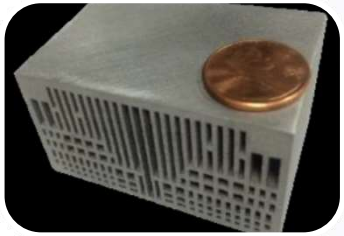
BiDFET based PV Inverter (NCSU)



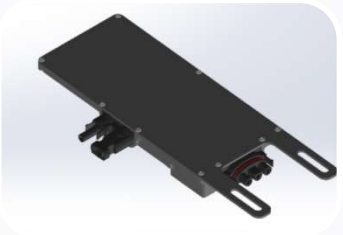
Transformer-less MV PEBB (University of Arkansas)



Multiport DC Transformer (GTech)



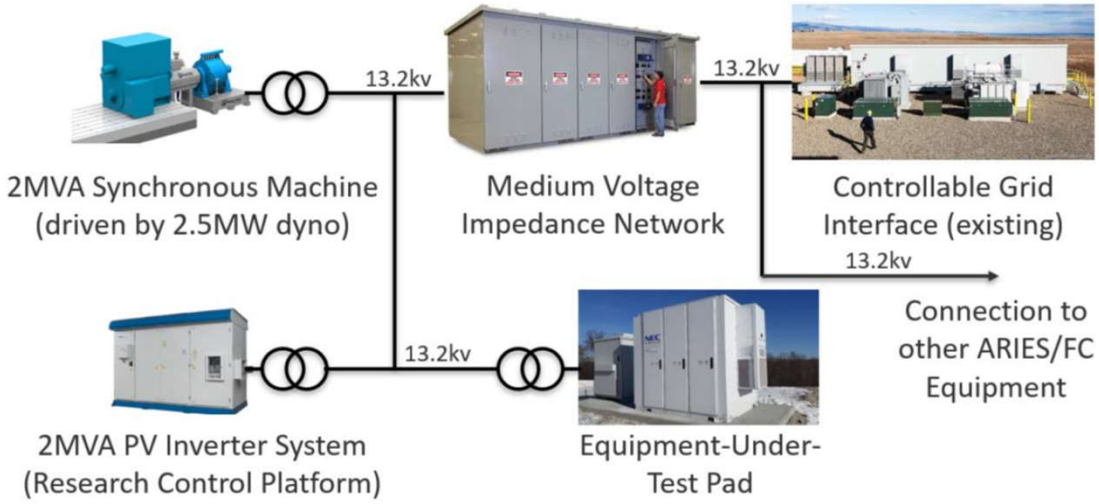
Heat Sink design with Additive Manufacturing (ONRL)



Highly-Reliable Residential PV Inverter (UMD)

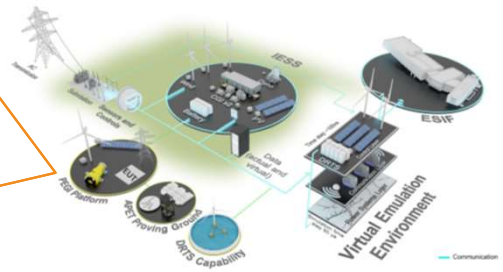
a) reductions in the lifetime costs
b) improve device reliability
c) enable versatile control functionalities

Power Electronics Grid Interface (PEGI)



Power Electronic Grid Interface (PEGI) Platform

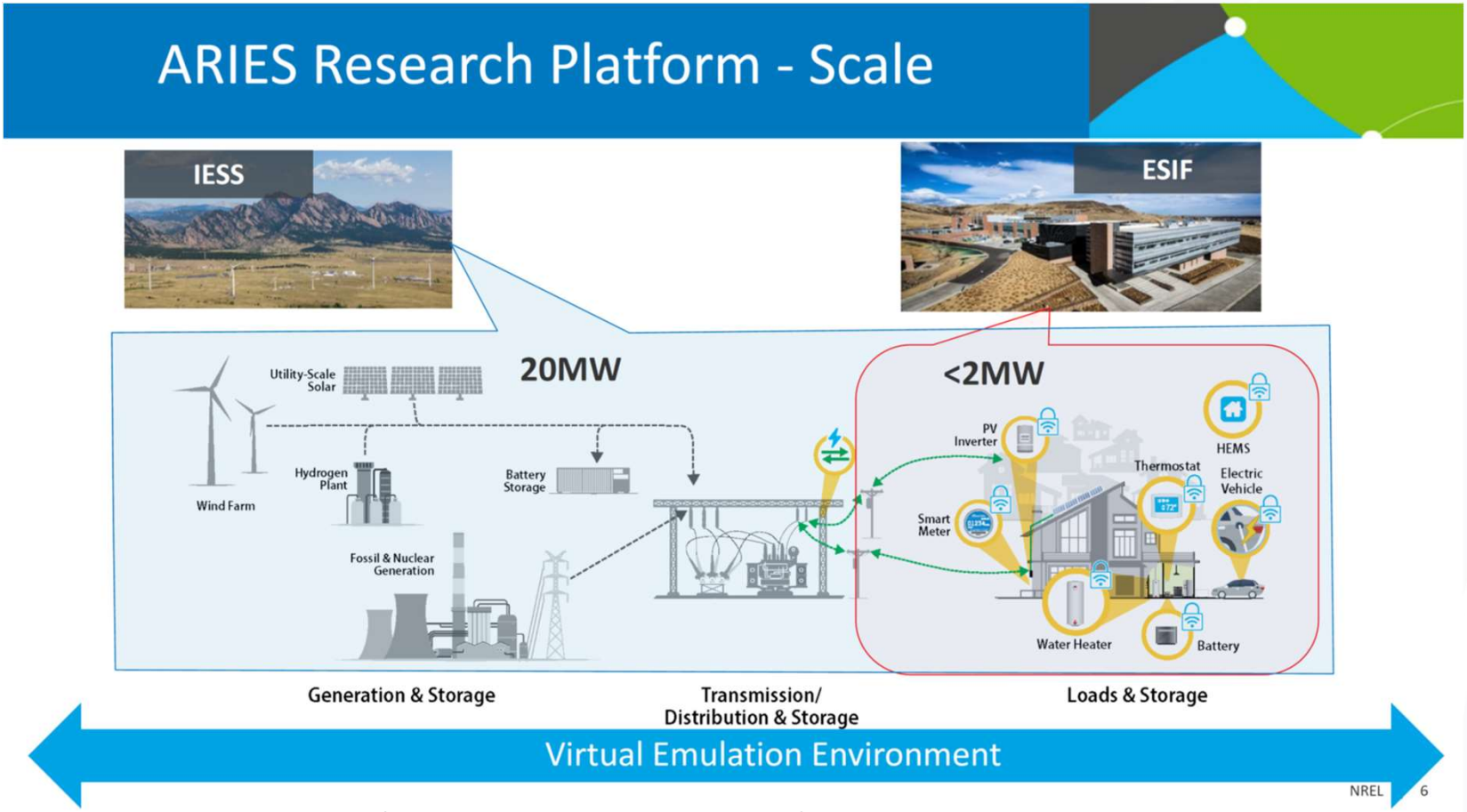
ARIES Campus



Power Electronics R&D Focused Capabilities

(Source: Barry Mather, NREL)

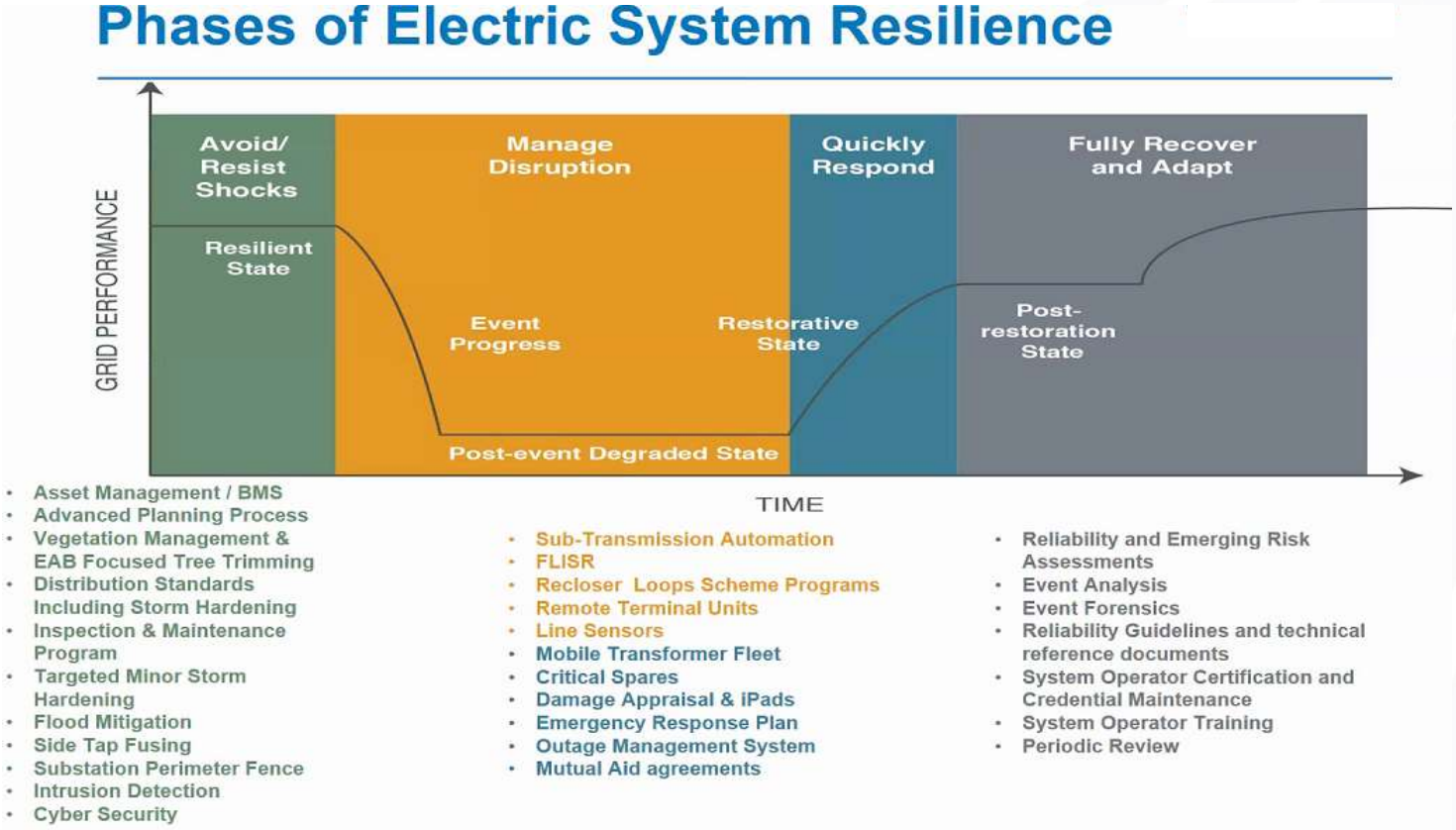
Investing in World Class Test Facility



(Source: Barry Mather, NREL)

PV for Resilience

Consequence-Based Resilient System Design



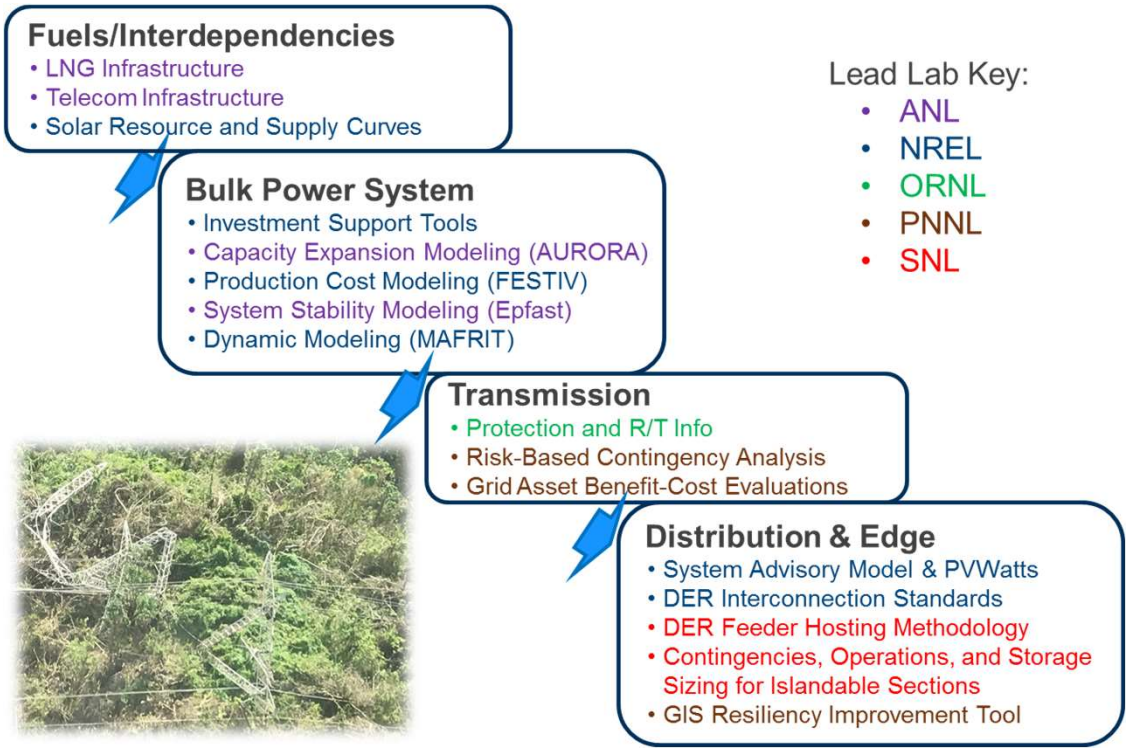
SNL (Jeffers, Broderick)

Building Resilient Power System in Puerto Rico

Objective: DOE Office of Electricity and SETO have tasked national laboratories to perform near-, medium-, and long-term modeling activities to support the rebuilding of a more resilient electric power grid system in Puerto Rico after the devastation of Hurricane Maria in late September 2017.

Phase 2 Approach:

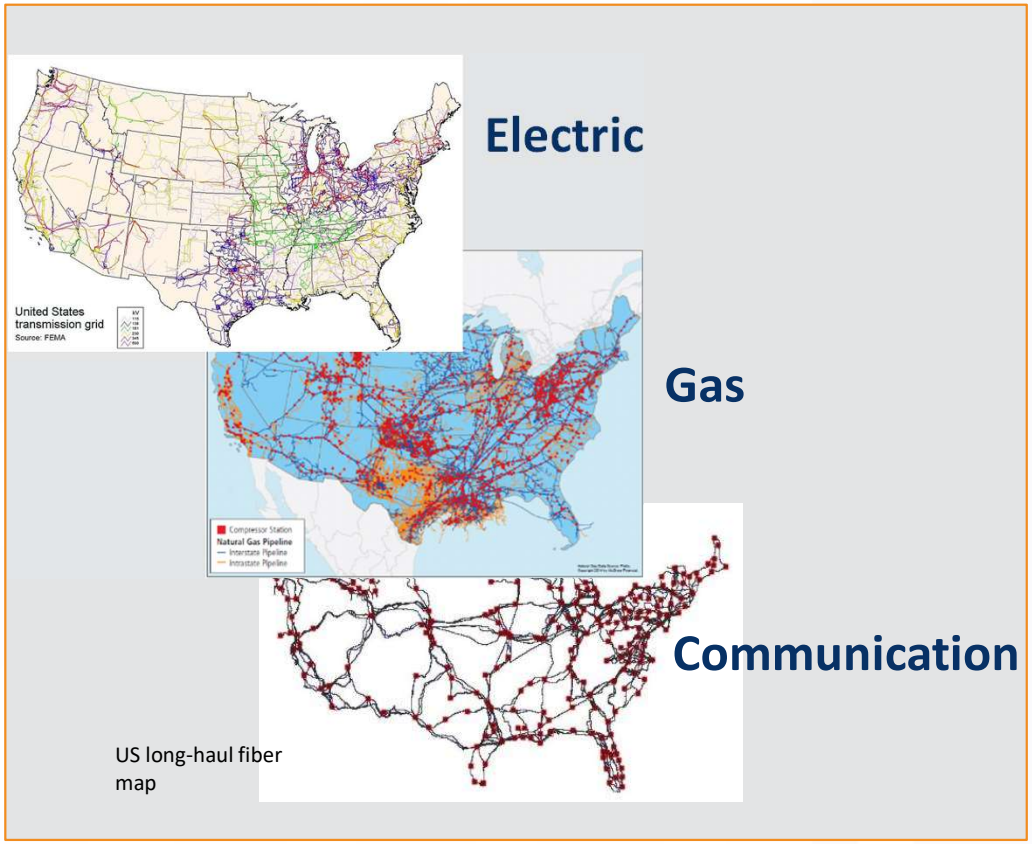
1. Build on insight from research in Hawaii and elsewhere
2. Develop integrated portfolio
3. Rigorous modeling and analysis
4. Broad stakeholder engagement (federal, state, local community, and industry)



North American Energy Resiliency Model (NAERM)

Goal: To identify electric critical infrastructure throughout North America and to **understand vulnerabilities and interdependencies with the interconnected system** to allow DOE to partner with industry, national labs, and other federal agencies to develop strategic initiatives to protect from cyber and physical threat while furthering energy dominance for the United States.

Collaboration with OE, Wind, and Water Technology Offices



Grid Resilience with a 100% Renewable Microgrid

Project Description

- **Goal:** Advance the state of the art in grid resilience demonstrating a 100% renewable microgrid
- **Innovation:** 1) optimize distributed energy resource operations, 2) enable islanding operations powered only by renewable energy, 3) reduce PV curtailment from islanding operations.
- **Approach:** 1) Install **grid-forming inverters + ESS** to support seamless islanding and blackstart without diesel backup generators. 2) **Field test and validate** an enhanced microgrid control system. 3) enhance the Real-Time Digital Simulator (RTDS) model for the Borrego Springs Microgrid; leverage power hardware in the loop **(PHIL) simulation**.

SDG&E Borrego Spring Microgrid

(~40MW solar, 1.5MW/3MWh BESS, fuel cell, electrolyzer, backup diesel gensets)



Cybersecurity

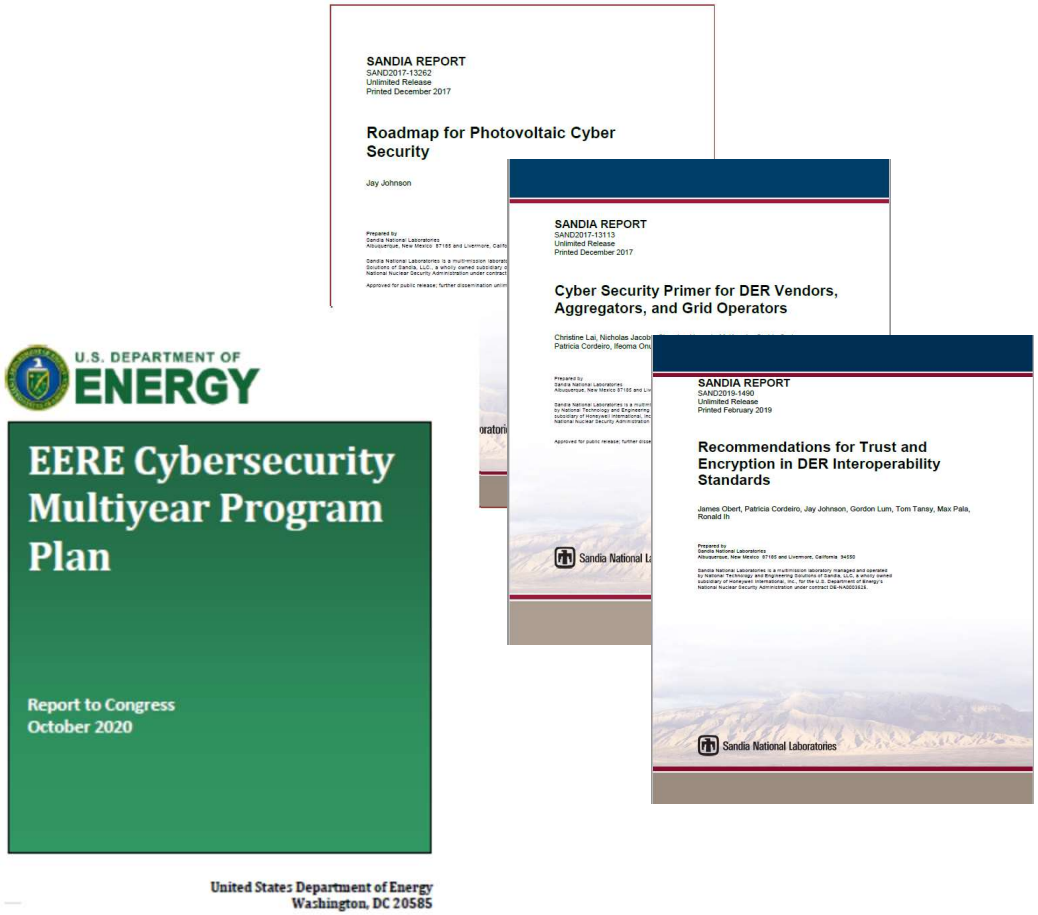
Cybersecurity a Key Challenge and an EERE Priority

Goal 1: Accelerate Cyber Resilience R&D of EERE Operational Technologies

- **1.1 Improve cybersecurity defenses and resilience.**
- **1.2 Mitigate vulnerabilities**
- **1.3 Next-generation cyber resilient technologies.**

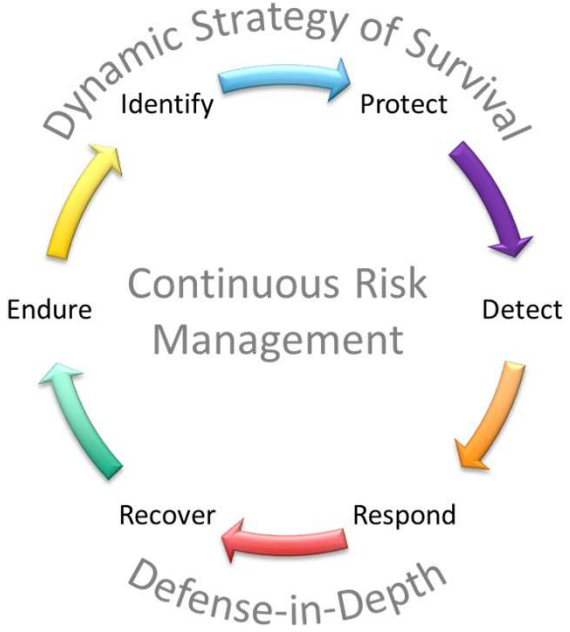
Goal 2: Increase EERE Stakeholder Cybersecurity Awareness

- **2.1 Improve situational awareness.**
- **2.2 Enhance EERE technology cybersecurity maturity.**
- **2.3 Identify opportunities for EERE stakeholder participation in cyber incident response exercises.**



Cybersecurity Strategy for Solar Integration

- Develop a **holistic approach** in information technology (IT) and operation technology (OT) risk management
  - Apply NIST Cyber Security Framework (CSF) and DOE's cybersecurity maturity model (ES-C2M2)
  - moving from a cybersecurity approach that focuses primarily on utility companies to one that includes endpoint device manufacturers and third-party system integrators.
- Build community awareness and **information sharing** mechanisms
  - equipment standards and vigorous testing, validation, and certification
  - supply chain cybersecurity, e.g. solar inverters and control software
- Leverage **DOE and national labs** technical expertise, research and testing facilities, and funding resources
- **Collaboration** within DOE and with other federal agencies, state and local, and industry
  - November 2021 : SETO-SEIA Cybersecurity Summit: Securing Our Solar Future Today
  - SETO funded project to work with NARUC and NASEO to develop state solar cybersecurity toolkits.
  - Ongoing INL-SEIA partnership



. Adapted from Jovanna Helms at LLNL

https://www.nist.gov/programs-projects/cybersecurity-framework

https://www.nist.gov/document/2018-04-16frameworkv11core1xlsx

Firmware Cybersecurity Analysis Tools and Capabilities

5.1.1 Firmware Command and Control Innovation and Impact

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

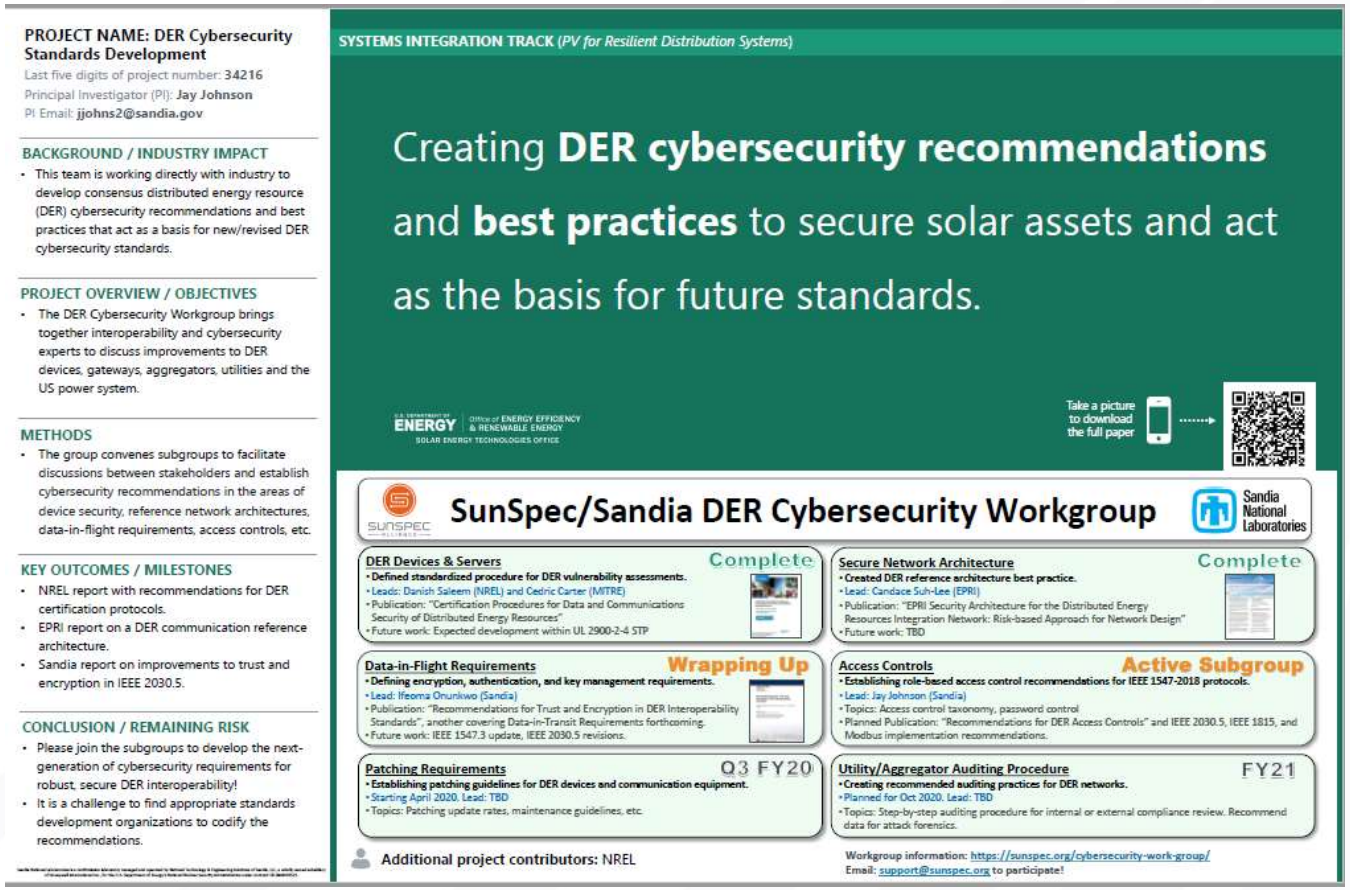
- ✓ **Innovation:** ML based firmware baselines show all functions used; agile embedded response integrated with bi-directional sharing of structured threat to security operations enable the protection of the electric grid critical functions
  - ✓ Current state of the art: reloading firmware when unexplained behavior is observed; without firmware monitoring; manual sharing of static indicators with field device operations
- ✓ **Contributions Advancing the State of the Art:**
  - ✓ Insight into embedded systems operations
  - ✓ Operate through detection and remediation vs offline reloads of firmware;
  - ✓ In-situ response; Detection based on ML firmware code behaviors;
  - ✓ Connectivity to Upstream Data Analytics
- ✓ **Impact:**
  - ✓ Visualized Firmware for Analysis provides insights previously unknown
  - ✓ Agile Embedded Detection and Response


Firmware pulled, reverse engineered and loaded into a GraphDB

- ✓ **Firmware C2 will share indicators locally and remotely with upstream energy security operations centers; identify adverse conditions indicating a cyber attack with response while maintaining operational functionality**

(Source: Rita Foster, INL)

DER Cybersecurity Standards Development



(Source: Jay Johnson, SNL)

AI/ML and Data Analytics

Apply Data Science and Advanced Computing Technologies

- **Don’t lose sight of the problems to solve**
  - Solar forecasting, control optimization, threat detection
  - Data science and AI/ML as enabling technologies
  - Energy system is a cyber-physical system with IT/OT
- **Leverage multiple computing platforms**
  - high performance computing (HPC)
  - public and private cloud
  - edge computing, embedded computing, quantum computing
- **Practical consideration**
  - Balance complexity with practicality
  - Combine data- and physics-based techniques
  - Transition from lab research to real world
  - Standard data interfaces for interoperability
- **Data management**
  - Respect data privacy and security
  - Education and collaboration
  - Collaboration: OE, AITO, NSF, NOAA, industry, Office of Science/ASCR

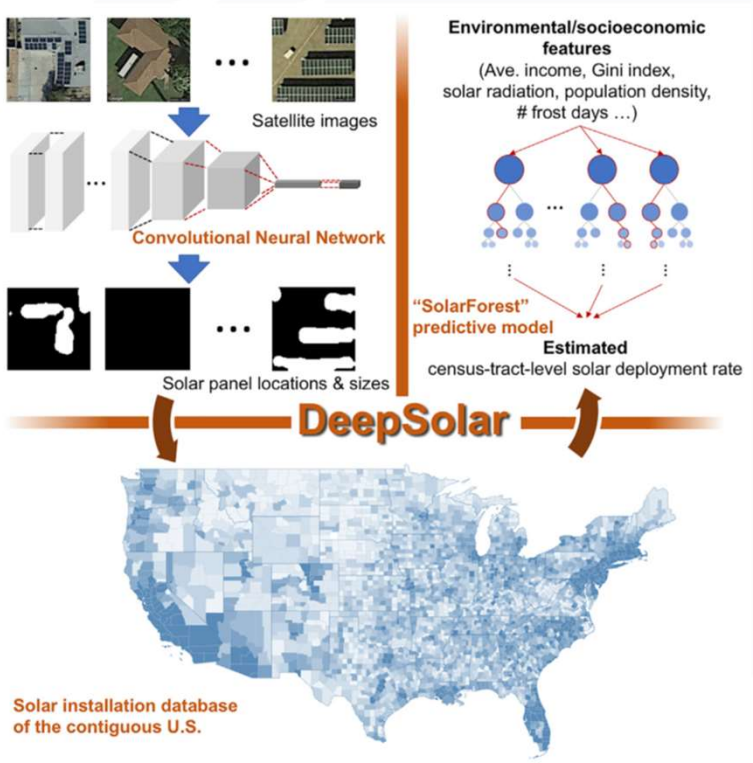


DeepSolar

Stanford is currently working on a SETO-funded project to apply CNN techniques to public and multi-modal data, including satellite imagery and street views, to develop a high-fidelity database which maps solar energy resources (including temporal and subtype information) and the associated infrastructure. This is built on the previous DeepSolar deep learning framework to automatically localize solar photovoltaic panels from satellite imagery and estimate their sizes.

By the numbers

Typical image tile size	15 m – 22 m
Typical image resolution	15 cm
Training set	~370,000 images
Validation set	~13,000
Test set	93,500
Total Installations in U.S.	1,470,000
Prediction accuracy	~90%



Jiafan Yu, Zhecheng Wang, Arun Majumdar, and Ram Rajagopal, ***Joule*** *2, 2605–2617, December 19, 2018*

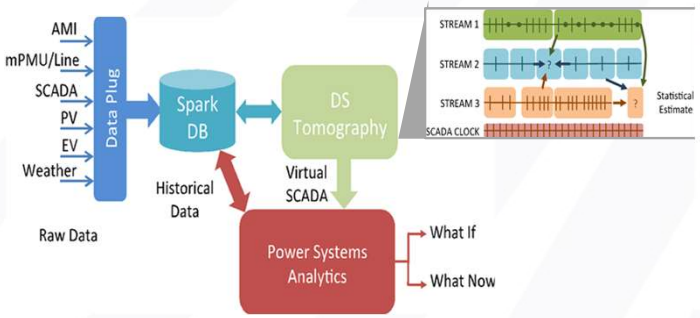
Apply AI/ML Technologies in Solar Grid Integration

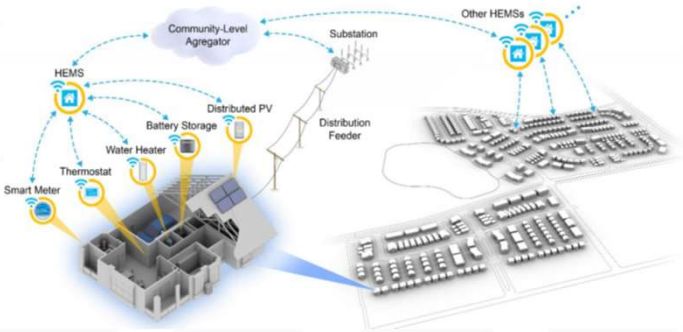
- **IBM Watt-SUN** Using machine-learning, the same technology behind the Jeopardy! playing robot Watson, IBM improved solar forecasting accuracy by as much as 30%.

- **SLAC** Developing a suite of open-source software tools to enable utilities to **anticipate, absorb and recover** from extreme events, applying AI and ML for distribution grid planning and monitoring (i.e. ML-based power flow, switch detection, solar disaggregation, forecasting, topology detection, network re-configuration)

- **NREL** Using smart meter data and AI techniques, the team develops algorithms that can learn to identify homeowner preferences and enable day-ahead load schedules. The algorithms evaluate how to best use variable solar energy to pair with flexible building loads like electric water heating or electric vehicle charging.







In Summary

- Key SI programmatic goal:
  - Develop technologies and solutions to enable the **reliable, resilient and secure operation of a 100% clean energy grid.**
- Top priorities
  - Advance inverter-based technologies to provide essential grid reliability services.
  - Develop cybersecurity tools to protect solar assets and electricity grid.
  - Apply ML/AI and data analytics methods in system planning and operation
- Support DOE's implementation of **Infrastructure Investment and Jobs Act (IIJA))** provisions



(Source: NREL Image Gallery)

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

2022 SETO PEER REVIEW





Soft Costs Balance of Systems

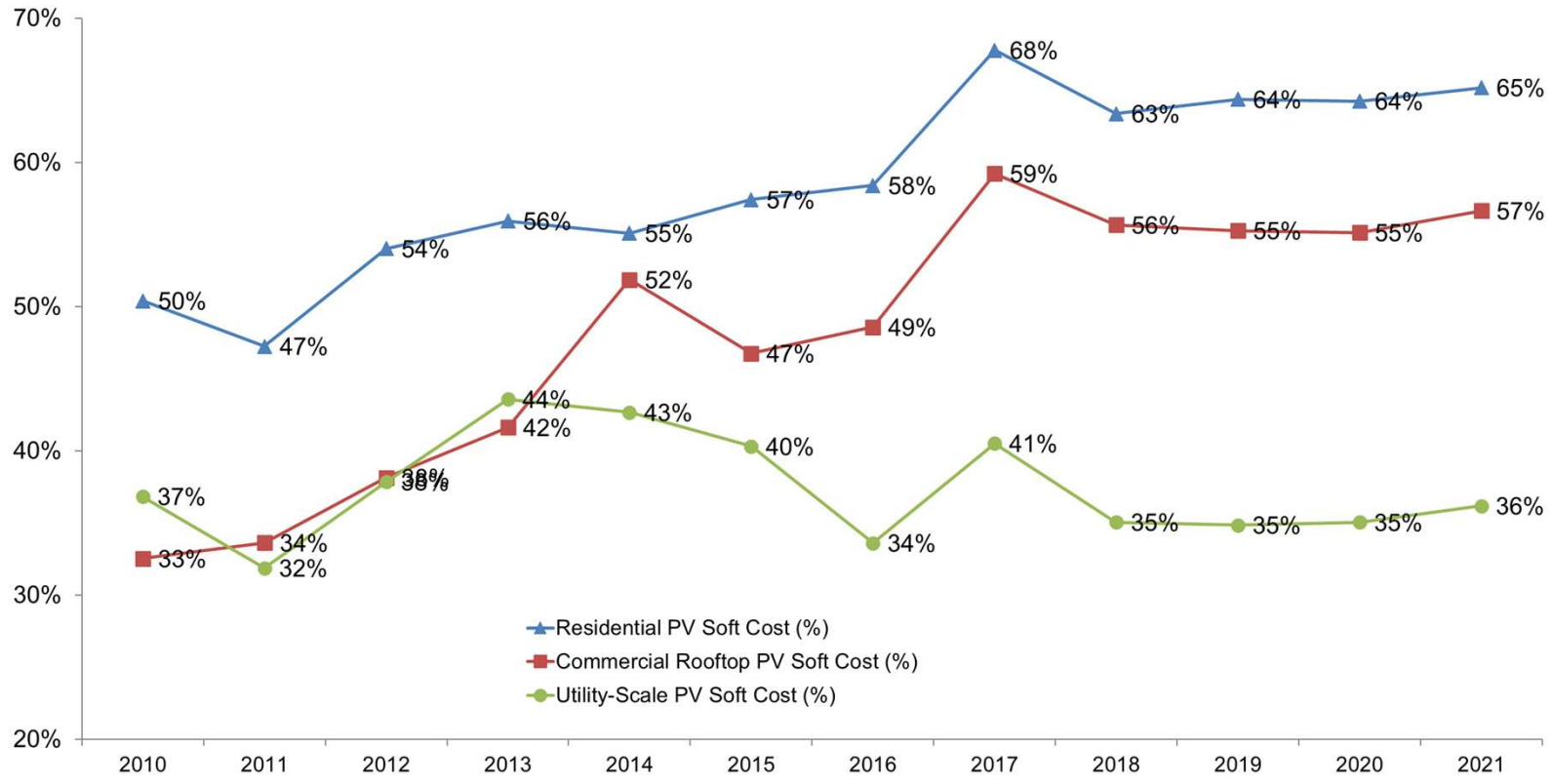
Michele Boyd

Program Manager, Strategic Analysis and Institutional Support

Nicole Steele

Program Manager, Workforce and Equitable Access

Solar Soft Costs (as Percentage of Total Cost)

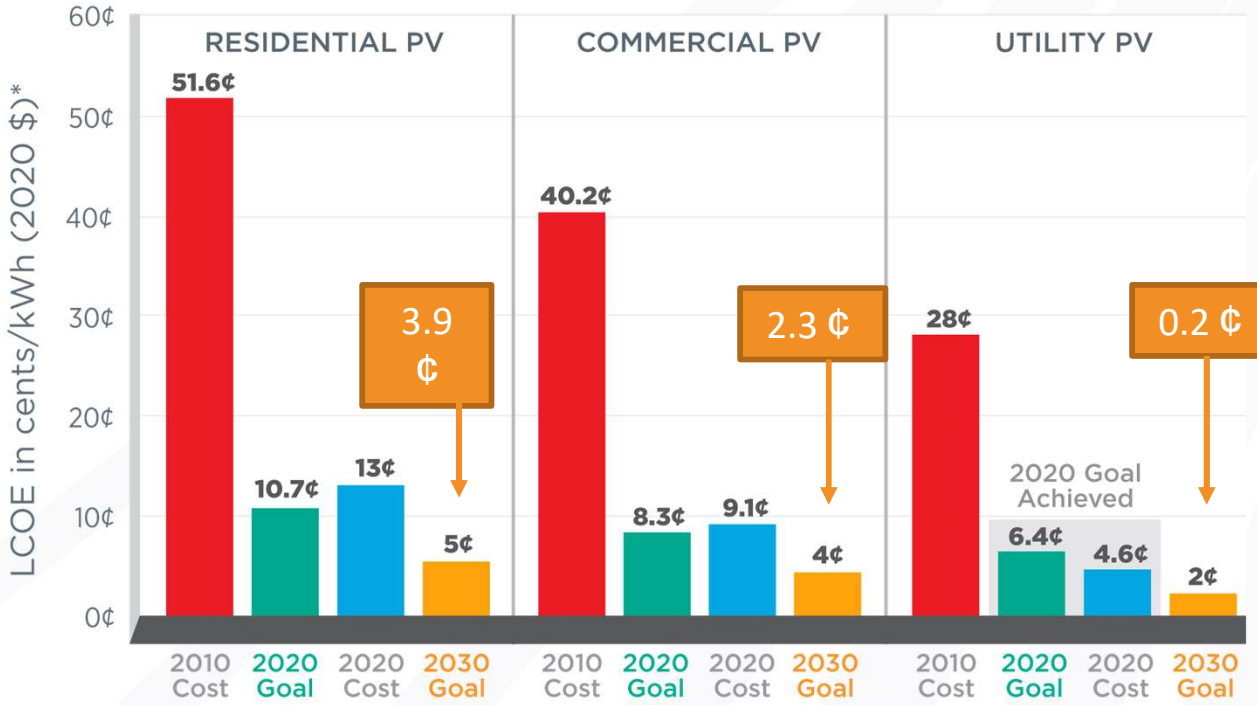


Source: National Renewable Energy Laboratory "U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2021."

Progress and Goals: 2030 Photovoltaics Goals

Reducing soft costs is key to reaching SETO's 2030 cost goals.

Solar Energy Technology Office Progress and Goals for Photovolatics (PV)



Potential reductions from soft costs

SETO Multi-year Program Plan Goals (2025)

Lowering the cost of Electricity from PV

- LCOE less than $0.10/kWh for residential PV and $0.08/kWh for commercial PV

Growing the U.S. solar industry

- Diverse solar workforce meets the needs of the industry and of disadvantaged communities and grows to employ at least 300,000 workers

Reducing the life cycle impacts of solar energy

- Environmental impact of PV technology, prioritized based on a life cycle impacts





Opening new markets

- 1 GWAC of PV installed in 2025 is combined with another use, such as agriculture or building structures

Ensuring that solar energy benefits all

- 100% of U.S. energy consumers can choose residential solar or community solar that does not increase their electricity cost

www.energy.gov/eere/solar/articles/solar-energy-technologies-office-multi-year-program-plan

Soft Costs Topic Areas

Permitting, Inspection, and Interconnection

- Improve permitting and inspection for rooftop solar, as well as interconnection of solar to the distribution and transmission grids

Solar Siting and the Environment

- Overcome barriers to siting large-scale solar, including understanding solar-environmental interactions

Data, Analysis, and Tools

- Collect and develop data, analysis, models, and user tools to help solar stakeholders overcome a range of barriers to solar deployment

Solar Energy Access

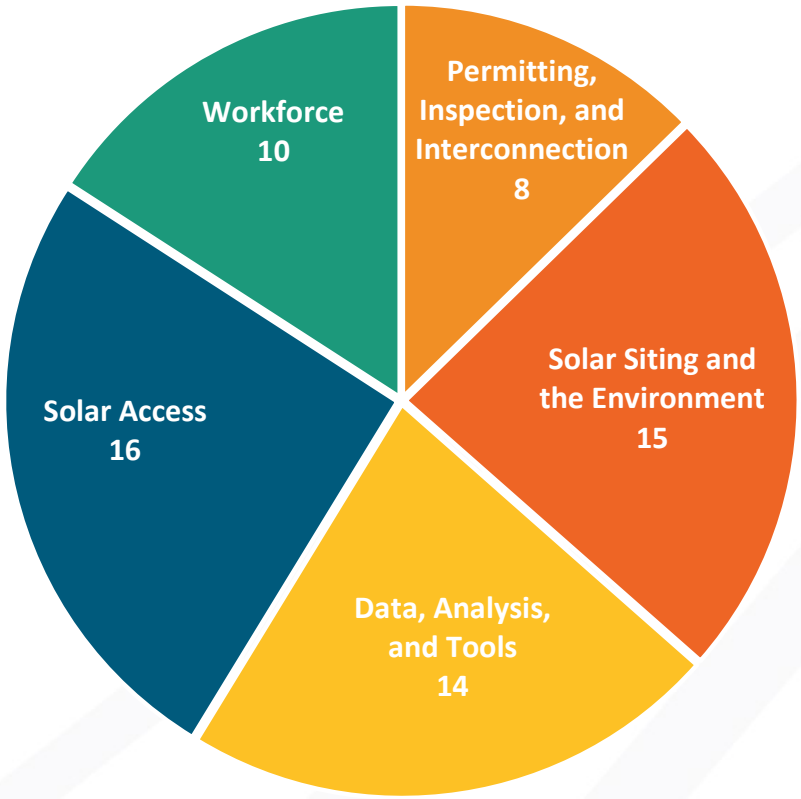
- Increase access to the benefits of solar energy, especially in underserved communities

Workforce

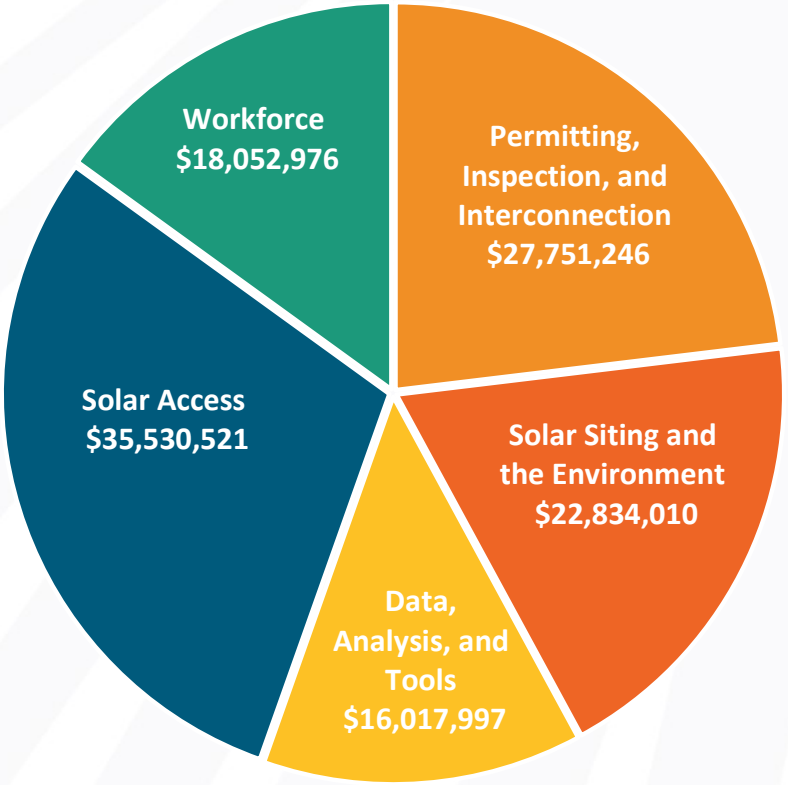
- Ensure a diverse, well-trained, and well-paid solar energy workforce that can meet the needs of the industry and of disadvantaged communities

Soft Costs Portfolio - Award Breakdown

Soft Costs Projects (#) by Topic Area



Soft Costs Funding ($) by Topic Area



Strategic Analysis and Institutional Support Team


Michele Boyd


Christopher Anderson


Shay Banton


Juan Botero


Krysta Dummit


Zachary Eldredge


Rebecca Glaser


Andrew Graves


Tiffany Jones


Caroline McGregor


Tomiwa Olufolabi


Ammar Qusaibaty


Abigail Randall


Daniel Sodano


Diana Sun

Workforce and Equitable Access Team


Nicole Steele


Anna Balzer


Benjamin Burch


Ariel Drehobl


Jamal Ferguson


Andrew Graves


Tomiwa Olufolabi


Chani Vines


Sarah Wilder

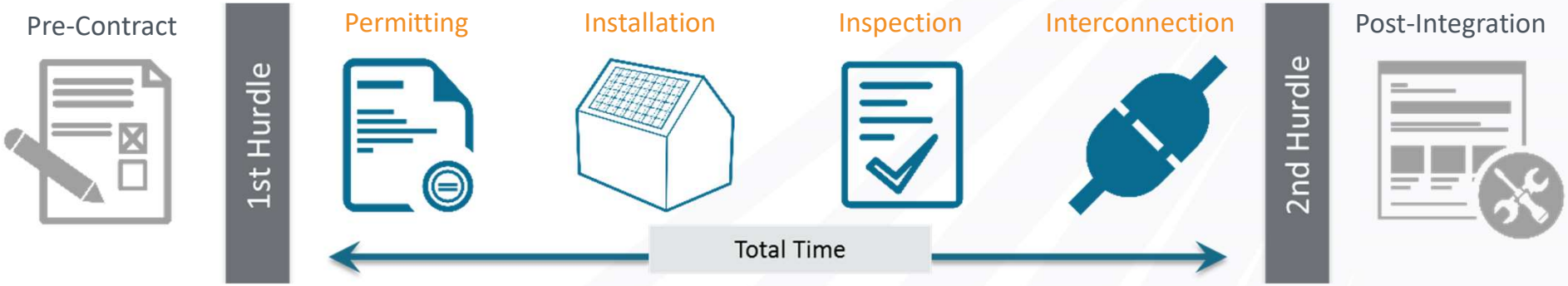

Diana Sun

Extensive Stakeholder Engagement

- **20 Stakeholder workshops**
  - Community Solar (13)
  - Interconnection (2)
  - Solar-Wildlife Interactions (2)
  - Solar Workforce (4)
  - Energy resilience (with SI team)
  - PV End of Life (with PV team)
- **2 DOE Co-sponsorship of Events**
  - AWWI Solar-Wildlife Symposium
  - Behavior Energy and Climate Change conference
  - NCSP Annual Summit
- **External Event Presentations**
  - Webinars
  - Conferences (virtual)
- **4 Requests for Information**
  - Equitable Access to Community Solar
  - PV End-of-Life
  - Solar-Wildlife Interactions
  - Solar Workforce Development
- **Federal agency collaboration**
  - HHS, HUD, USDA, DOL, USFWS
  - OMB – Pilot Justice40 program
  - USDA-DOE Workshop on Agrivoltaics (2)
- **State collaboration**
  - State Energy Offices
  - State Wildlife Agencies

Permitting, Inspection, and Interconnection (PII)

Time Wasted is Costly to Consumers and Market



If every system installed is delayed unnecessarily by just one day, the cost to the market will be approximately

$4.7 M/day*

*Lost revenue from electricity sales. Calculations based on 2020 deployment level, assuming historic average irradiance of electricity generation a day and at weighted average retail price of $0.06 per kWh.

PI Strategy – Rooftop Residential Solar

Goal: Reduce PI timelines and soft costs; streamline and improve PI processes in order to accelerate solar deployment across the U.S.

Priorities:

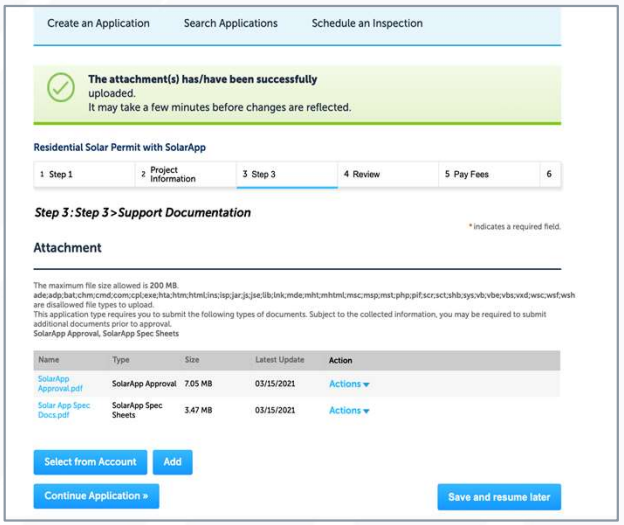
- Broad geographic reach, while advancing equity and diversity goals
- Balanced focus between integrating new technologies, while meeting baseline standards
- Emphasize data collection and analysis that demonstrates impact, particularly for PI timelines and costs



Solar Automated Permitting Process (SolarAPP+)

A web-based tool for permitting residential PV (and storage) systems at no cost to local jurisdictions

- Evaluate applications for **safety and code compliance**.
- Enable **standardization** of permitting processes.
- Deliver **automated**, instant plan review and **permit approval**
- Provide a clear **inspection checklist** to streamline inspection processes
- **Integrate with existing software** platform(s)
- **Incorporate energy storage** and expand to other market segments.
- Focused **TA for underserved communities**



➢ **Results from a recent analysis of 5 pilot communities found that SolarAPP+ sped up the PI timeline by 12 days and saved more than 2,300 hours in local staff time.**

SolSmart

SolSmart is a national recognition and technical assistance program for local governments to streamline processes and make it easier for residents and businesses to go solar in their community.

Designation

- SolSmart uses objective criteria to designate communities that have successfully met theses goals.
- **Over 400 cities and counties** have received designations of SolSmart Gold, Silver, and Bronze



165

Gold Designees

109

Silver Designees



150

Bronze Designees

424

Designees

(as of January 2022)

Technical Assistance

- Program participants are eligible for **technical assistance** from a team of national experts to help achieve the SolSmart designation.

Next Steps for SolSmart

- This spring, SETO plans to announce $10M in awards to continue the program another 5 years, with a focus on equity goals and other new priorities.

SolSmart is led by:

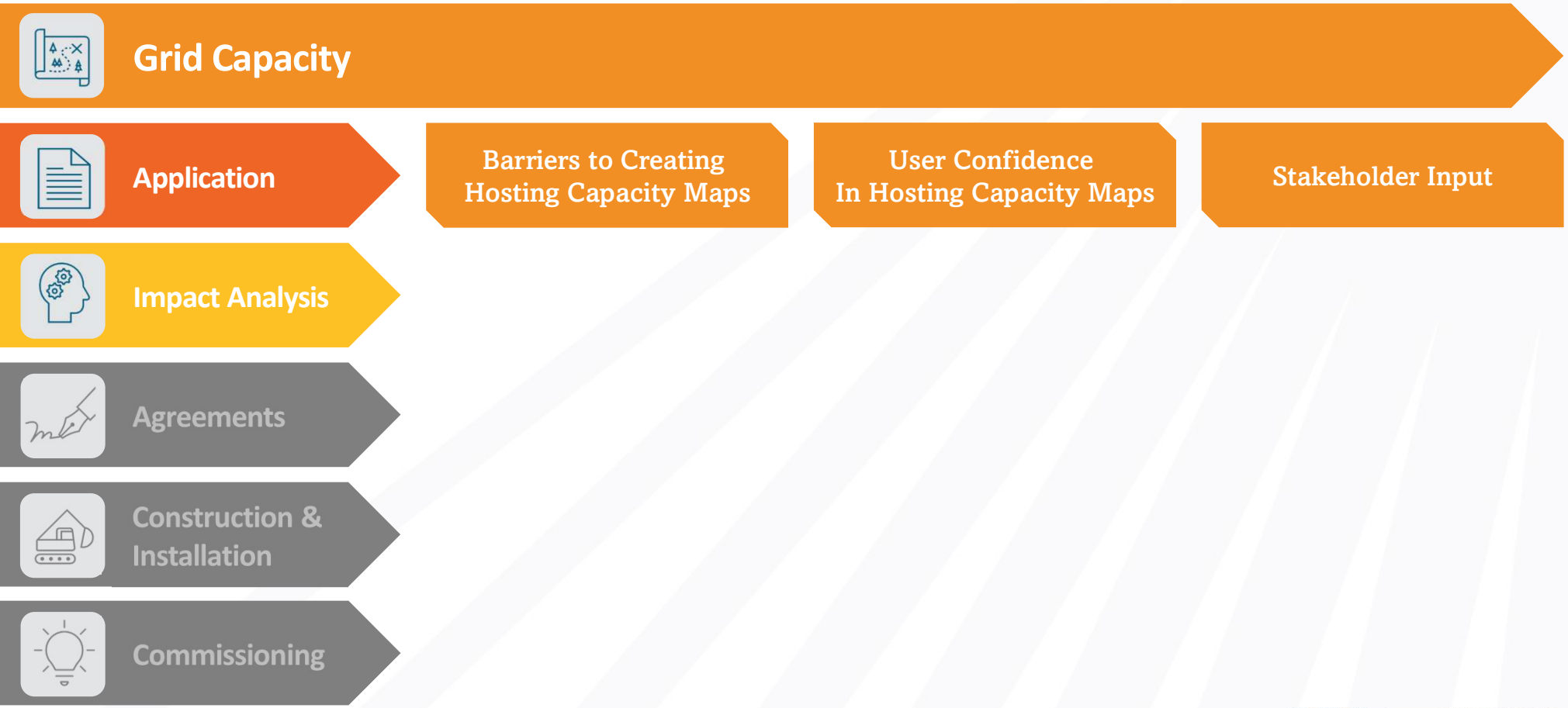
IREC

ICMA INTERNATIONAL CITY/COUNTY MANAGEMENT ASSOCIATION

Interconnection Portfolio Overview



Interconnection Portfolio Overview



Interconnection Portfolio Overview



Grid Capacity



Application



Impact Analysis



Agreements



Construction & Installation



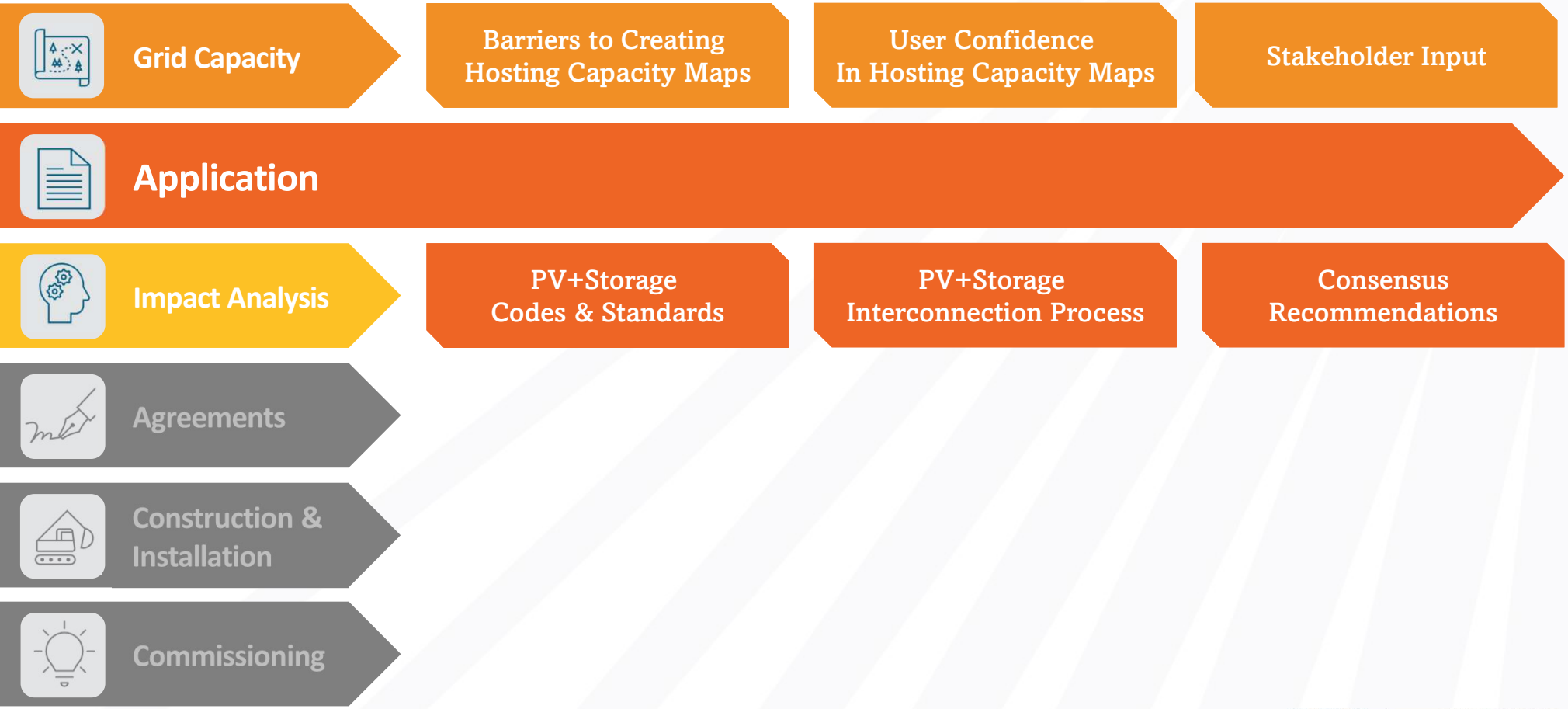
Commissioning

Barriers to Creating Hosting Capacity Maps

User Confidence In Hosting Capacity Maps

Stakeholder Input

Interconnection Portfolio Overview



Interconnection Portfolio Overview



Grid Capacity

Barriers to Creating Hosting Capacity Maps

User Confidence In Hosting Capacity Maps

Stakeholder Input



Application

PV+Storage Codes & Standards

PV+Storage Interconnection Process

Consensus Recommendations



Impact Analysis



Agreements



Construction & Installation



Commissioning

Interconnection Portfolio Overview



Grid Capacity

Barriers to Creating Hosting Capacity Maps

User Confidence In Hosting Capacity Maps

Stakeholder Input



Application

PV+Storage Codes & Standards

PV+Storage Interconnection Process

Consensus Recommendations



Impact Analysis



Agreements

Operational Flexibility Impacts of PV+ Storage

Interconnection Cost Drivers

Technical Assistance on IEEE 1547-2018



Construction & Installation



Commissioning

Interconnection Portfolio Overview

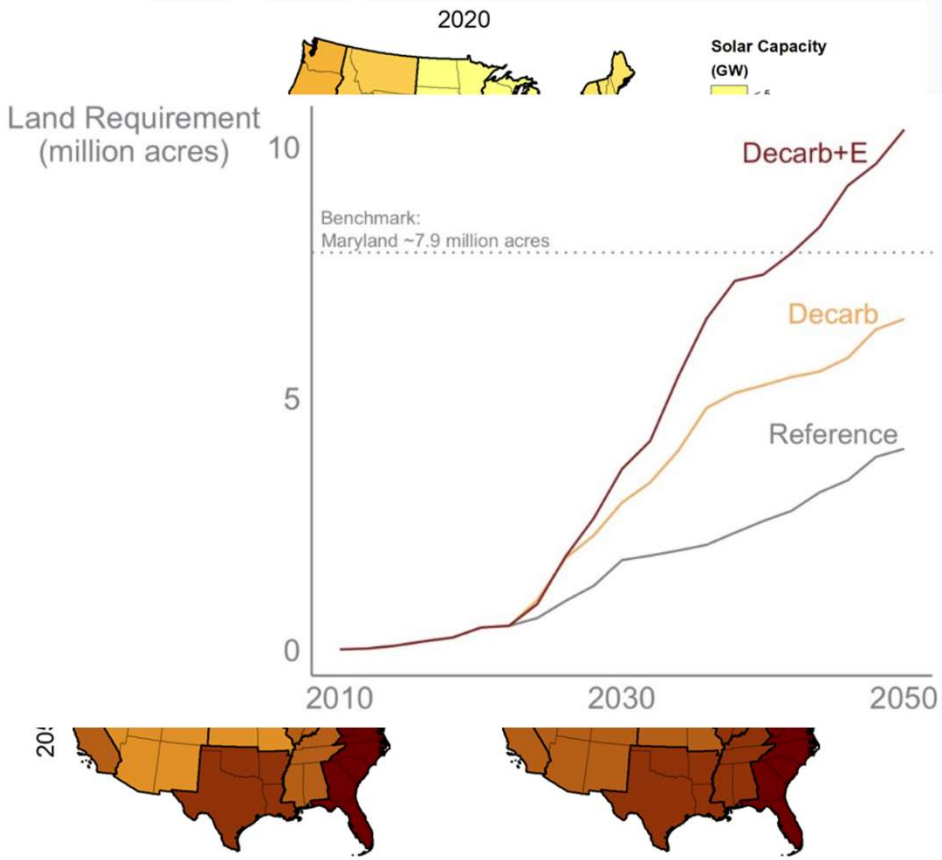
Grid Capacity	Barriers to Creating Hosting Capacity Maps	User Confidence In Hosting Capacity Maps	Stakeholder Input
Application	PV+Storage Codes & Standards	PV+Storage Interconnection Process	Consensus Recommendations
Impact Analysis	Operational Flexibility Impacts of PV+ Storage	Interconnection Cost Drivers	Technical Assistance on IEEE 1547-2018
Agreements			
Construction & Installation			
Commissioning			

The current portfolio is focused on improving the first three steps of the interconnection process through thought leadership, innovative practices, technical assistance, and stakeholder engagement.

Solar Siting and the Environment

Solar Futures Study: Lots of Solar to Site

- In *SFS* scenarios, every Census region has more solar in 2035 than the highest regions do today
- Lots of capacity deployed in Georgia, Florida, Texas -- these regions are less prepared than more mature markets (CA, AZ).
- Ground-mounted solar is projected to require about **5.7 million acres** by 2035 (0.3%), increasing to as much as **10 million acres** in 2050 (0.5%)



Solar Friction in Local Communities


The New York Times

He Set Up a Big Solar Farm. His Neighbors Hated It.

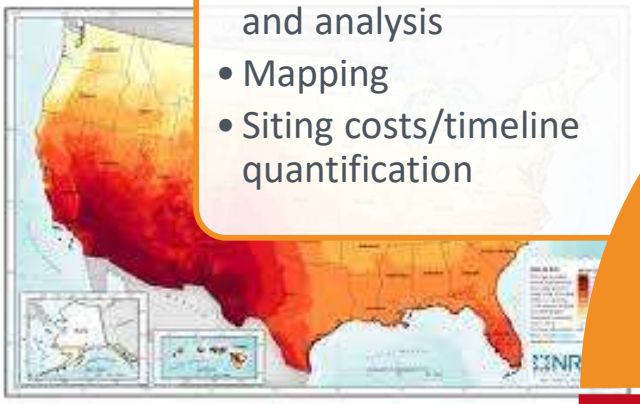
A push toward renewable energy is facing resistance in rural areas where conspicuous panels are affecting vistas and squeezing small farmers.


Locals Worry Wind and Solar Will Gobble Up Forests and Farms


Voices Across America

Opinion: Solar energy's luster dims in rural southern Ohio

Solar Siting Research Framework



- Land use modeling and analysis
- Mapping
- Siting costs/timeline quantification

Foundational Data and Analysis

Social Benefits and Costs

- Economic impacts (jobs, revenue)
- Stakeholder perceptions/ knowledge flows
- Community-driven siting





Innovative Siting Solutions

Environmental Benefits and Costs



- Floating solar
- Agrivoltaics (pollinators, grazing, and crops)
- Solar on contaminated lands and mine lands

- Wildlife
- Native vegetation
- Water and soil quality
- PV End of life
- Carbon emissions

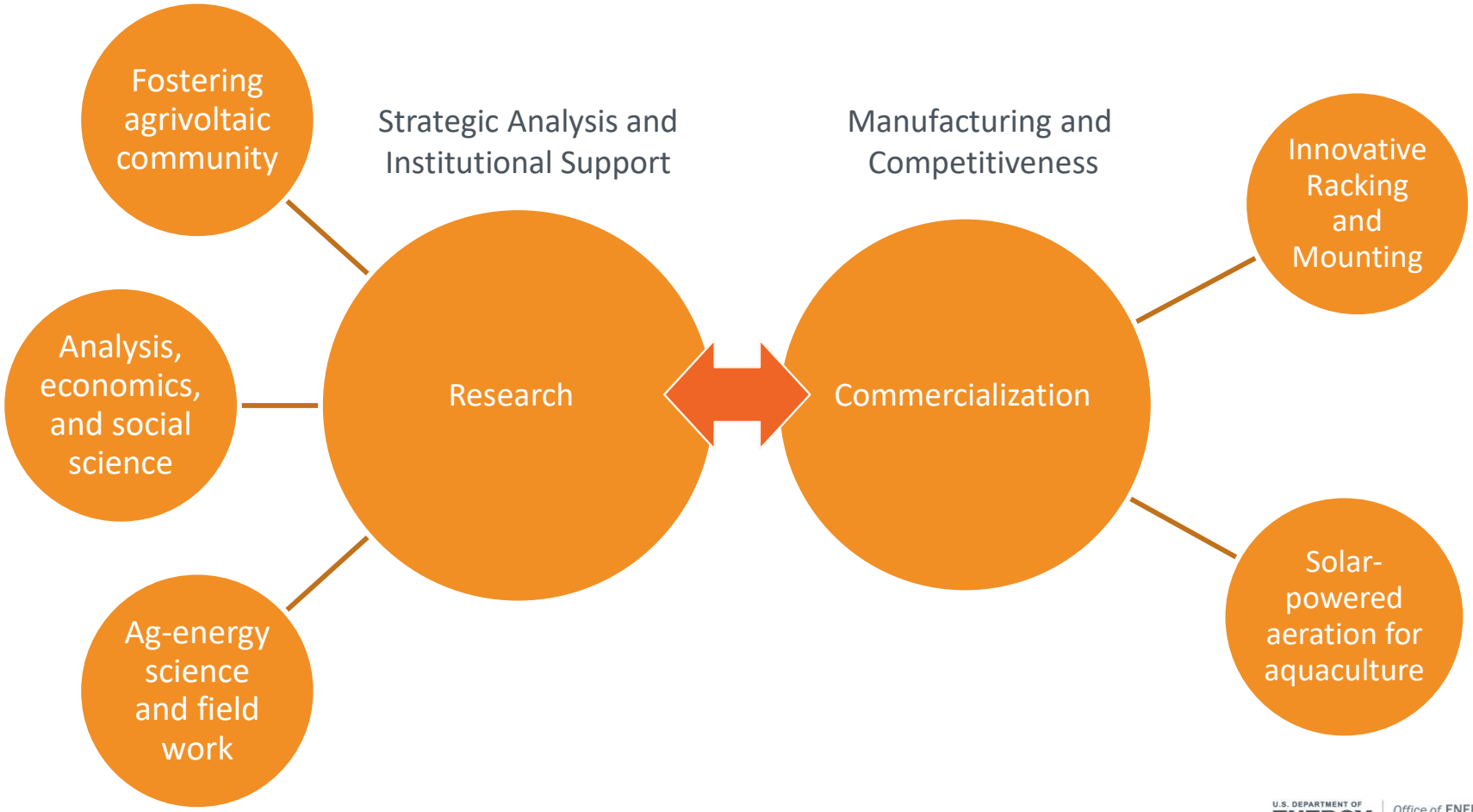
Spotlight #1: Agrivoltaics = Agriculture + Photovoltaics

Can solar be combined on the same land with agriculture to the benefit of both agriculture and solar energy?

- Agriculture is defined as crops, livestock and/or pollinator habitat
- Potential benefits for farmers:
  - Provide diversified revenue
  - Reduce irrigation water needs
  - Improve crop yield, especially in dry areas
  - Improve resistance to extreme weather, such as droughts
- Potential benefits for solar industry:
  - Reduce land-use competition
  - Improve panel performance
  - Lower solar O&M costs



SETO Research and Commercialization Activities in Agrivoltaics



NREL InSPIRE 3.0

InSPIRE 3.0 provides research and thought leadership to enable the expansion of agrivoltaics

Field Research

- Evaluate crop performance and irrigation savings in different geographies, configurations, and crops
- Study agrivoltaics using bifacial panels
- Evaluate ecosystem services, including pollinator diversity/abundance, wildlife habitat, soil health
- Develop solar-sheep grazing guidelines

Foundational Analysis and Data

- Develop research protocols and research roadmap
- Conduct economic analysis of scaling to multi-MW installations
- Track growth of the sector and trends/patterns
- Build on InSPIRE data portal and website

Thought leadership

- Grow ASTRO network
- Host a conference on agrivoltaics
- Assist with interagency collaboration (USDA, DOI)



InSPIRE research team on-site in Minnesota

Other SETO Agrivoltaics Work (FY20 FOA)



National Center for Appropriate Technologies

- Building an AgriSolar Clearinghouse to connect practitioners with resources and each other

Silicon Ranch

- Exploring solar combined with rotational cattle grazing in Georgia



University of Illinois – Chicago

- Scaling pollinator-friendly solar ground cover to large (10MW+) projects



University of Massachusetts – Amherst

- Studying agrivoltaic farm performance and economics across the state on multiple crop types

Each project is 3 years; total $7M in funding

Spotlight #2: Avian-Solar Interactions

- Avian interactions with utility-scale solar facilities (PV and CSP) are **not well-understood** → **delays** in project approvals and/or **increased costs** for monitoring and mitigation
- Better understanding of the **types** and **magnitude** of avian-solar interactions is needed to:
  - **Minimize negative impacts** on avian species and populations; **maximize positive impacts** (e.g., ecosystem services)
  - **Improve solar facility siting**
  - **Support well-informed agency decisions** (permitting, mitigation, and conservation requirements)
  - **Minimize soft costs** due to permitting delays and monitoring/mitigation
- **Widely shared data, methods, and technologies are needed to better understand and mitigate impacts**
  - Biological studies to determine avian impacts at solar facilities are **expensive, time-consuming and often not conclusive**

Current SETO Avian Work (FY19 FOA)



Argonne National Lab

- Developing an AI-based edge computing camera system which identifies, tracks, and classifies avian activities at solar sites



Electric Power Research Institute

- Developing drone and LIDAR technology which can be used to track and monitor avian activity at solar sites automatically



University of California – Los Angeles

- Developing genetic analysis techniques to understand species and population impacts based on remains found at solar sites

Beyond Birds

- As solar has expanded, questions have arisen about solar interactions with other taxa and species (e.g., ungulates, gopher tortoises).
- In 2021, SETO:
  - Conducted stakeholder workshops (Summer/Fall 2021)
  - Released RFI (Fall 2021.) Summary here.
  - Co-sponsored AWWI (now REWI) "Symposium on Solar and Wildlife/Natural Resources" (December 2021), 600 attendees





Data, Analysis, and Tools

Data, Models, and Analysis Areas of Focus

Data Resources & Management

- Open Energy Data Initiative (big data lakes)
- O&M field data in climate zones
- Data standards and multi-DER evaluation for resilience planning

Tech Optimization / Adoption Models

- Technology Integration cost and optimization (REopt, SAM)
- Simulation tools for scheduling solar + storage power plants
- Customer adoption model (dGen)

Solar Market Analysis

- National solar market data collection and trends analysis
- Southeast solar + storage planning
- EE + PV + storage metrics and analytics

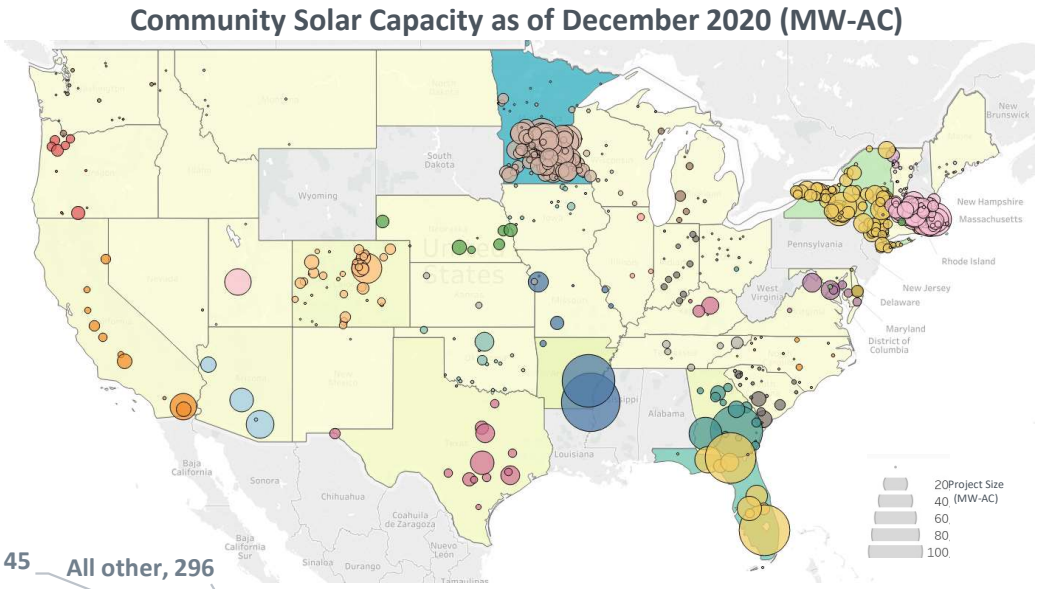
Social Science Analysis

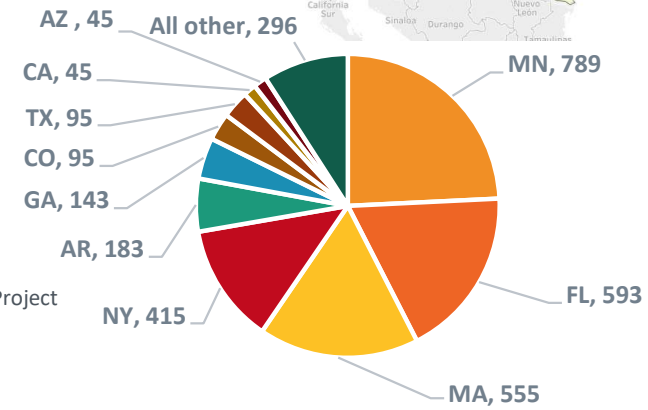
- Co-adoption of solar + storage, EVs and EE
- Knowledge flow of solar energy
- Solar cybersecurity learning via public-private institutional engagements

Equitable Access to Solar

Community Solar Market is Growing but Remains Highly Segmented

- >5.02 GW-AC, 1,900 projects located in 39 states and Washington, D.C.
- Cumulative community solar capacity has grown by about 121% year over year since 2010, in other words, capacity has more than doubled on average year over year
- About 1.6 GW came online in 2021 alone
- >90% of cumulative capacity is located in 10 states





Source: Heeter, Jenny; Xu, Kaifeng; Chan, Gabriel (2021): Sharing the Sun Community Solar Project Data (Dec 2020, Revision). National Renewable Energy Laboratory. https://data.nrel.gov/submissions/167

National Community Solar Partnership Overview

Increased Stakeholder Engagement

JULY: 55 responses to Equitable Community Solar RFI

JULY-AUGUST: 30 states participated in a series of 3 State Convenings

SEPTEMBER: 75 organizations participated in a series of 2 Community-Focused Organization Convenings

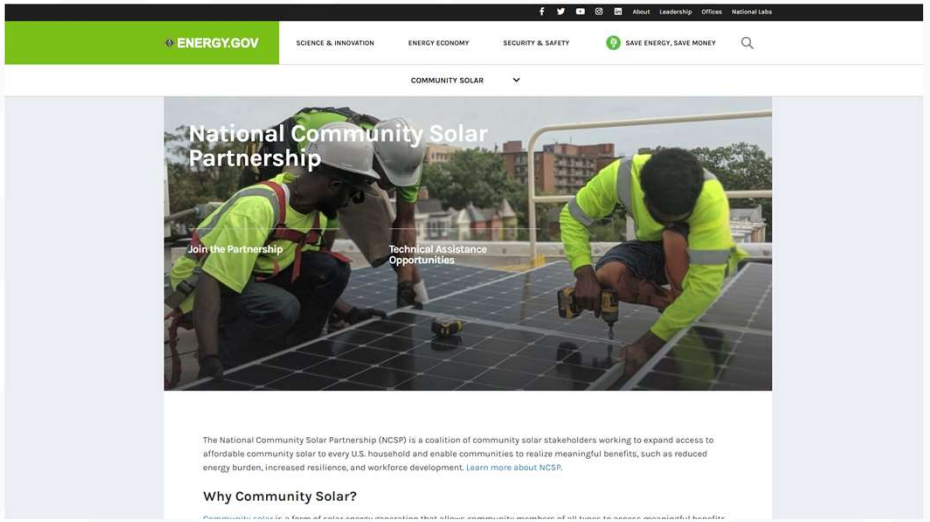
AUGUST – NOVEMBER: Over 50 conversations with lenders and philanthropy partners

NOVEMBER: 15 CEO/business leaders participated in Business Leader Roundtable

DECEMBER: Over 40 participants in Credit Ready Solar Lender Kickoff; 21 conversations with State Energy Offices

JANUARY: Over 630 participants in NCSP Annual Summit; 20 participants in Credit Ready Solar Philanthropy Kickoff

Elevating Program Recognition



>800 PARTNERS

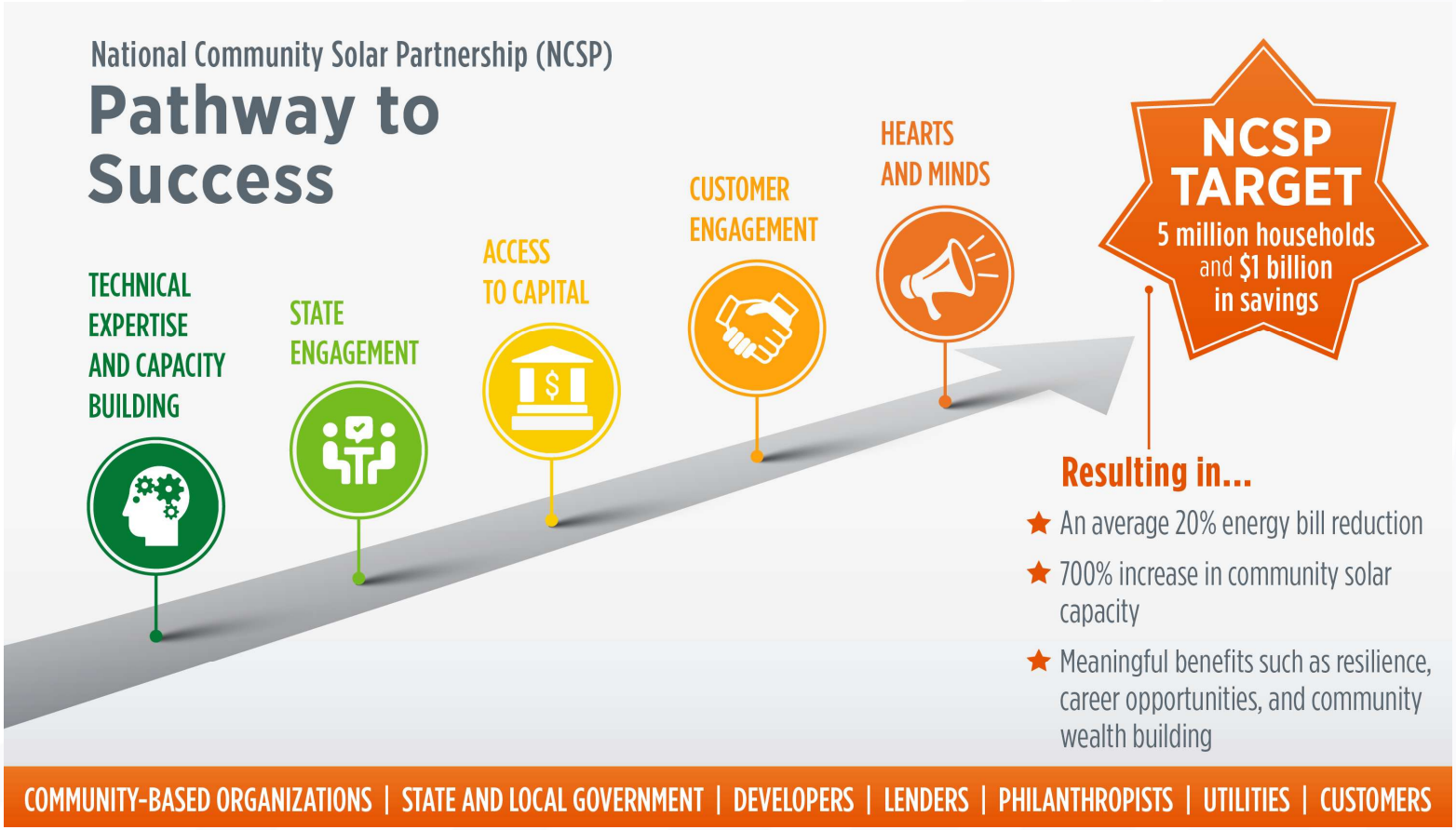
>500 ORGANIZATIONS

49 STATES

Barriers to Equitable Community Solar Deployment

Policy & Program Design	Financing & Funding	Capacity	Customer Subscriptions	Messaging & Communication	Siting & Interconnection
• Lack of enabling legislation • Program limits/caps to deployment • Restrictions set by utilities	• Monetizing tax credits • Lack of pre-development capital • Perceived risk • Difficult to find consistent affordable debt	• Limited staff time and expertise • Lack of training for long-term project operation & maintenance • Challenge of small project size	• Verifying low- to moderate-income households • Connecting customers with subscriptions • Streamlining process	• Standardizing language & messaging • Consumer protections • Recognizing successful projects and programs	• Identifying potential sites • Cost & wait time for interconnection • Resistance to or covenants banning solar development

Setting a New Target: To 5 Million & Beyond



Solar Energy Innovation Network

The Solar Energy Innovation Network is a collaborative research program that supports multi-stakeholder teams to research and share solutions to real-world challenges associated with solar energy adoption.

APPROACH

- Directly fund teams (up to $200,000) to work on community-driven innovative ideas
- Technical assistance (TA) and facilitation support to test those innovative ideas
- Peer networking to facilitate participant learning and strengthen outcomes
- TA to enable replication of solutions in other locations

SOLAR ENERGY INNOVATION NETWORK
U.S. DEPARTMENT OF ENERGY

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

ROUND 3 TOPIC : Equitable Adoption of Solar

- 8 teams working to overcome barriers related to (a) solar and storage for resilience, (b) solar and weatherization and energy efficiency programs, and (c) peer to peer solar outreach and education

BERKELEY LAB Lawrence Berkeley National Laboratory

RMI ENERGY. TRANSFORMED.

Products and tools are available at https://www.nrel.gov/solar/solar-energy-innovation-network.html

Access to Solar Financing Overview

Purpose

Across the nation, solar installations have soared for the last 10 years. However, a large number of households, businesses and communities are still unable to access clean affordable power. SETO is working to help ensure all Americans have access to affordable solar energy.

Solar energy can help to reduce energy burden, but only 15% of solar adopters are LMI communities due to barriers in ownership, financing, and information access.

Current Projects

- 11 current projects funded by FY18 and FY19 FOA
- Evaluate alternative solar financing models for low-income consumers
- Develop new tools and methods to better assess credit risk
- Engage community financial institutions and other capital sources to expand solar financing in low-income communities

Geographic Scope

Alternative Financial Models		
1	CO	Grid Alternatives
2	TX	Houston Advanced Research Ctr.
3	CO	ICAST
4	CO	NREL
5	MA	Solstice
6	NH	Univ. of New Hampshire

Local Solar Implementation Strategies		
7	AZ	Arizona State University
8	VT	Clean Energy State Alliance
9	VA	National Assn. State Energy Officials
10	VA	National Rural Electric Cooperative Assn.
11	DC	Groundswell

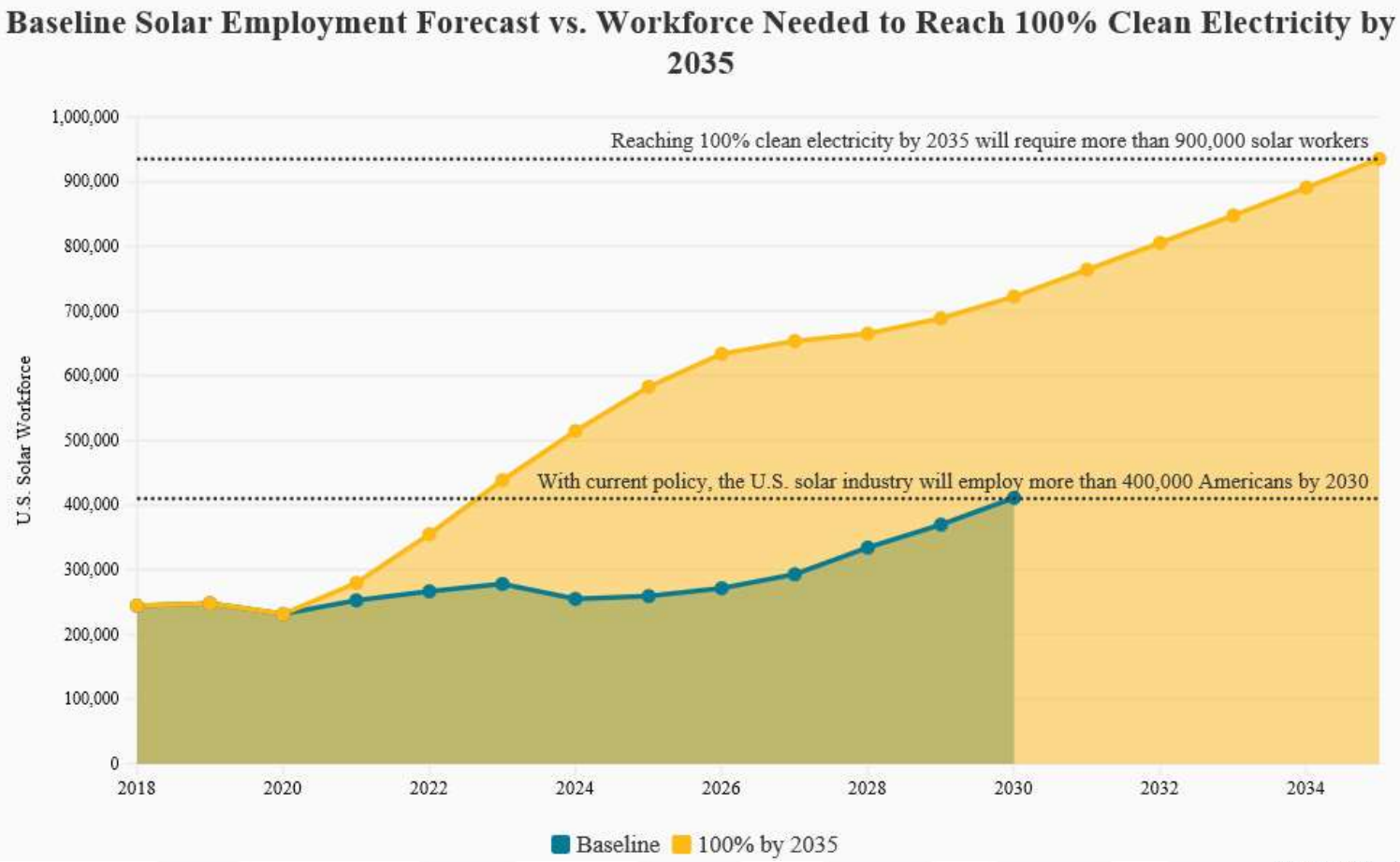


Portfolio Overview

GRID Alternatives San Diego	Shared solar financing model leveraging Program Related Investments (PRI)
ICAST	Aggregated shared solar financing model for market rate/unsubsidized MFAH projects
HARC	Activating opportunity zones for rapid solar+storage deployment in residential LI communities in Texas
NREL Transforming ENERGY	Designing and advancing a new class of financial products envisioned as flexible financial credit agreements (FFCAs)
SOLSTICE	Research on suitable community solar contract terms for different LMI customer segments and churn and default rates
University of New Hampshire Carsey School of Public Policy	Create training programs to enable community finance institutions to expand their engagement in solar finance in low-income communities
ASU Arizona State University	Developing socially and economically generative, resilient PV-energy systems for LMI communities in Puerto Rico
CleanEnergy States Alliance	State strategies to bring solar to LMI communities by researching new solar program designs and associated financing models
NASEO National Association of State Energy Officials	Inclusive Shared Solar Initiative (ISSI): leverage LIHEAP, state and local incentives, and other capital funding sources to promote LMI solar.
NRECA America's Electric Cooperatives	Achieving cooperative community equitable solar sources for rural electric cooperatives
Groundswell	Accelerating Low-Income Financing and Transactions for Solar Access Everywhere

Clean Energy Workforce

Future Workforce Needs



Source: National Solar Jobs Census 2020, Solar Energy Industries Association, May 2021

Workforce Program Overview

Enable the continued growth of the solar industry by funding workforce development programs, new analysis and outreach efforts, and convening multi-stakeholder and interagency dialogues.



Current Portfolio

- 8 current awards focused on residential installation
- Solar District Cup
- Training for first responder and building owners
- STEM-focused Fellowship, Post-doc programs

Current Activities

- RFI, stakeholder convenings, and Roundtable
- DOL Collaboration
- NREL Labor Market Analysis
- Future programs focused on multi-stakeholder partnership and advancing equity goals

Workforce Awards

Blue Lake Rancheria
- Native American Tribe in N. CA
- Partners with GRID Alternatives to provide hands-on installation training for NAs
- Capacity building workshops for Tribal Leaders

Safer
- Chicago-based organization focused on returning citizens
- Provides wrap-around training and support to transition Previously Incarcerated Individuals into the solar industry

Midwest Renewable Energy Association
- Partners with 5 local CC to offer NABCEP courses
- Engages with local installers to host student interns to provide on-the-job training

Solar Ready Vets
- The Solar Foundation partners with Hiring Our Heroes to provide corporate fellowships for transitioning military
- Partners with NABCEP and SEIA to build additional capacity for veterans to pursue solar careers



Philadelphia Energy Authority
- Public-private org. promoting clean energy solutions in PA
- Developed a solar program for a vocational high school in Philadelphia
- Partners with Youth Build Philly to provide solar internships for Opportunity Youth

SunSpec Alliance
- DER industry assoc. in CA
- Partners w/ UCSD to develop online training focused on DER cybersecurity and grid integration

Illinois Green Economy Network
- Consortium of 39 CC in IL focused on green careers
- Develop solar curriculum and expand recruitment efforts

Electric Power Research Institute
- Partners with 5 universities to develop new curriculum for grid operations focused on IT, AI, and cybersecurity

Future Workforce Program Priorities

Priorities	Description	Rationale
Industry-driven	Provide training for the jobs & skills the industry needs	• 57% of solar employers find it "somewhat/very difficult" to find qualified workers • Solar installation/project development jobs have increased by 269% over the past 10 years
Employee-centered	Support pathways to family supporting, prevailing wage careers	• Clean energy jobs already pay higher wages than other jobs requiring comparable education/training • Need to focus on transferrable skills and stackable credentials, that prepare individuals for clean energy careers
Diversity, Equity, and Inclusion	Increase diversity in the solar workforce and expand access for under-resourced communities	• Prioritize the Administration's EJ goals and the Justice40 Initiative • Minority groups, particularly African Americans (8% of the Solar WF, compared to 12% nationally), and woman are under-represented in the solar/clean energy workforce • Returning citizens, communities of color, and disadvantaged young people experience higher rates of unemployment and underemployment.

Source: National Solar Jobs Census 2019 and 2020, Solar Energy Industries Association

Break

15 minute break

Be Revolutionary: Brought to you in collaboration with WPTO

Frame.io

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

2022 SETO PEER REVIEW

Manufacturing & Competitiveness

Technology-to-Market Activities

energy.gov/solar-office

Markus E. Beck, M&C Program Manager

Fania Barwick, Andrew Dawson, Kyle Fricker, Peter Lobaccaro, Robert Meagley, Emanuele Pecora, George Stefopoulos, and David Ung

Manufacturing and Competitiveness Team


Markus Beck


Vanina “Nina” Alanes


Fania Barwick


Andrew Dawson


Kyle Fricker


Tiffany Jones


Peter Lobaccaro


Robert Meagley


Emanuele Pecora


George Stefopoulos


David Ung

Agenda

- The Role of RDD&C at SETO—Manufacturing & Tech-to-Market Objectives
- The M&C Toolbox—Programs and Activities
- Select Focus Areas and Portfolio Highlights
  - Mature Technologies
  - Emerging Technologies
  - Emerging Sectors

Manufacturing & Competitiveness



Mission Statement

Manufacturing and Competitiveness: Securing a Sustainable, Robust and Resilient Solar Supply Chain

The SETO Manufacturing and Competitiveness (M&C) subprogram supports solar research, development, demonstration and commercialization (RDD&C) activities to:

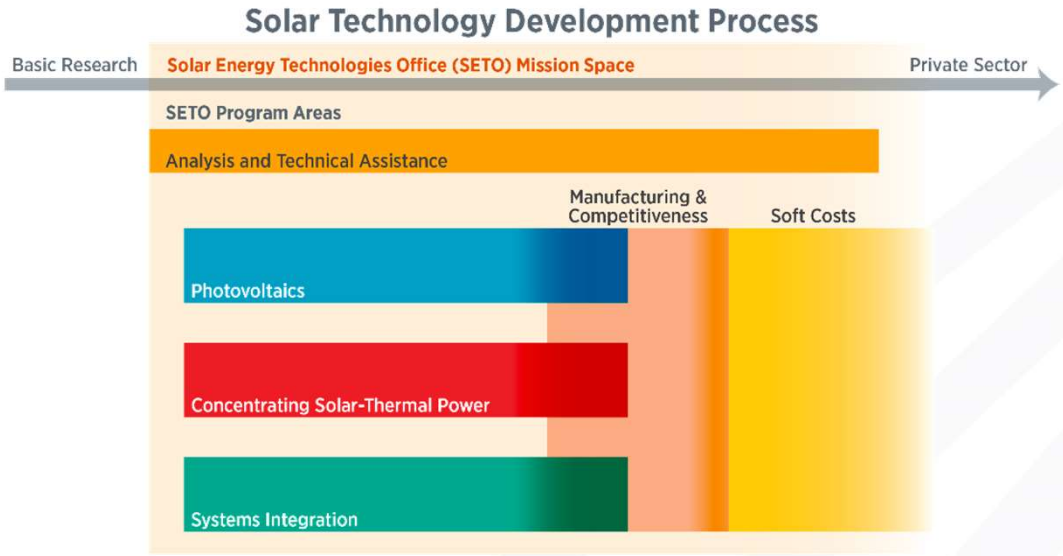
- Accelerate expansion of domestic manufacturing capacity
- Increase domestic content, value of solar products, and job creation across the entire supply chain;
- Advance innovative and impactful technologies and concepts;
- Reduce technical and commercial risk enabling greater private sector investment and scale; and
- Sustain and expand the solar innovation community to ensure technology leadership.

Programs cover a wide variety of technologies including photovoltaics, concentrating solar power, and power electronics. Programs target funding gaps that occur at various stages along the development cycle of new technologies; from conception to proof of concept, first article to low-volume production and market introduction, and ultimately high-volume manufacturing. Through inter-agency and inter-office collaborations M&C strives to accelerate the adoption and proliferation of innovative solar technologies.

M&C staff serve as experts to the public sector on solar technology RDD&C as well as the state of the domestic and international solar industries. M&C provides thought leadership to the R&D, entrepreneurial, and finance communities on technology evolution pathways, cost and performance requirements, and the competitive landscape.

M&C seeks to act in coordination with all relevant elements of the public and private RDD&C complex to ensure that the U.S. market has access to the materials, technologies, and products needed for a rapid, equitable, and sustained energy transition.

The Manufacturing & Competitiveness Program



Support businesses at all stages

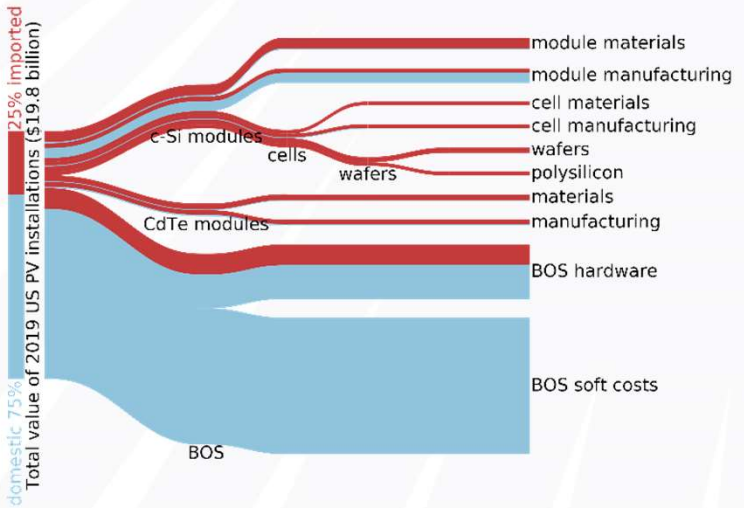
Collaborate with other technology offices and agencies

Engages in public-private partnerships to:

- Bring products out of the lab and closer to market
- Increase domestic manufacturing competitiveness
- Generate domestic value across the entire solar value chain
- Develop tools to lower costs and increase deployment

Context

- FY20 & FY21 M&C budget $60M
  - Congressional Direction $20M to be spent each on PVSK and CdTe each FY
- Prior administrations focus early-stage R&D
- Absence of consistent, long-term industry policy focused on establishing domestic content across the entire solar supply chain
- Domestic PV manufacturing capacity
  - Polysilicon 20-30GW$_{DC}$
  - Ingot, wafer, c-Si cells NONE
  - CdTe 2.3GW$_{DC}$
  - c-Si module assembly 4.7GW$_{DC}$
  - Inverters ~0.3-0.5GW$_{DC}$
  - Solar glass NONE
- At present the U.S. lacks a viable and mature solar supply chain



The value of a typical utility-scale PV system in the U.S. broken into its components. The thickness of each line is proportional to its monetary value. System installation includes all upfront system costs other than module and BOS. Red indicates imported content and blue indicates domestic content.

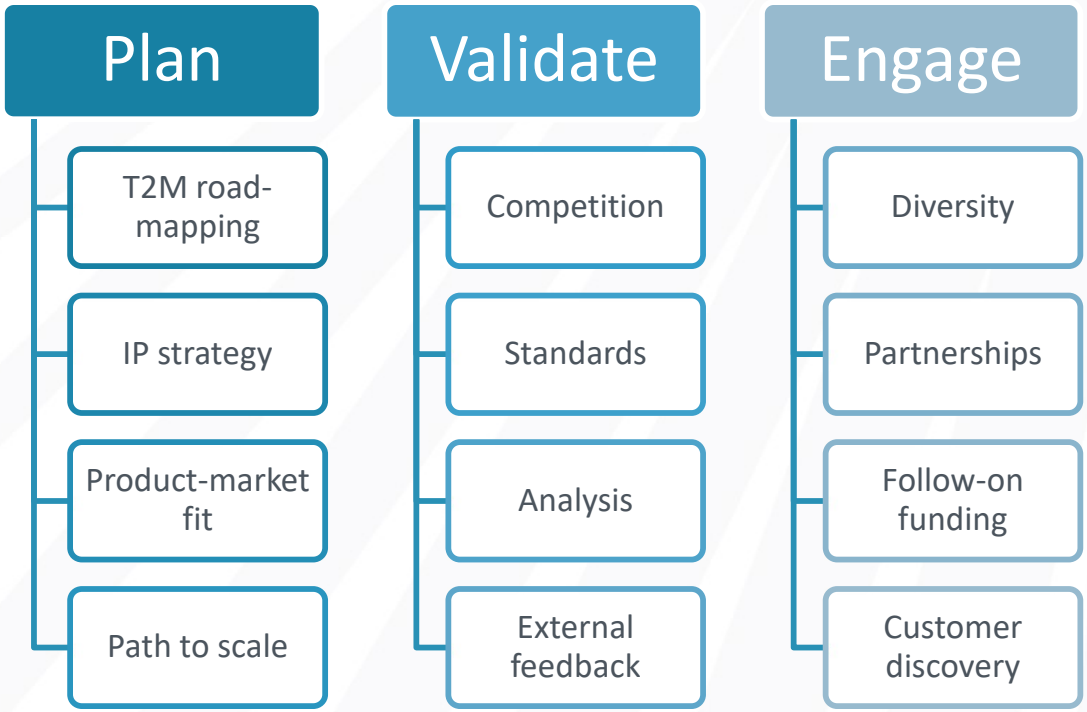
M&C T2M Project Approach

Promote activities that amplify the impact of R&D projects and enable technology transformations from prototypes to real-world, viable solutions (the D&C).

Research & Development

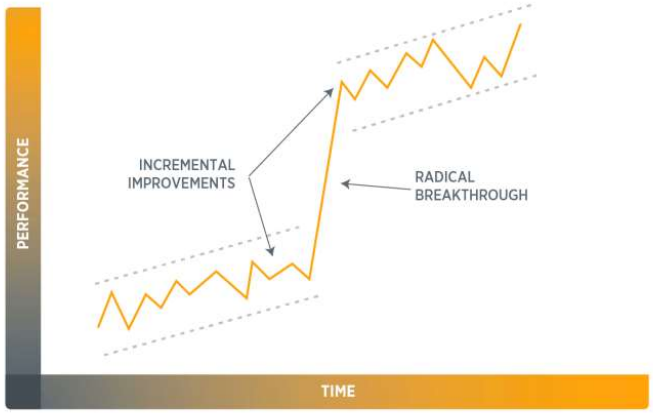
Demonstration & Commercialization

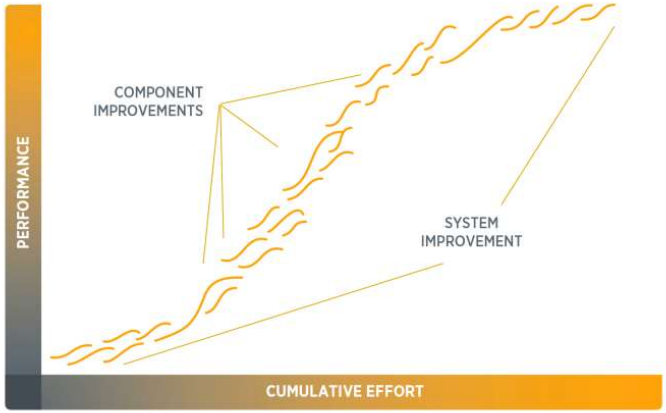
Market-relevant and self-sustaining technology



The Objective of Technology-to-Market Activities

- If the research we fund does not reach the market then it has little to no impact.
- If we fund things that would have reached the market on the same timeline without our funding we are also having little to no impact.

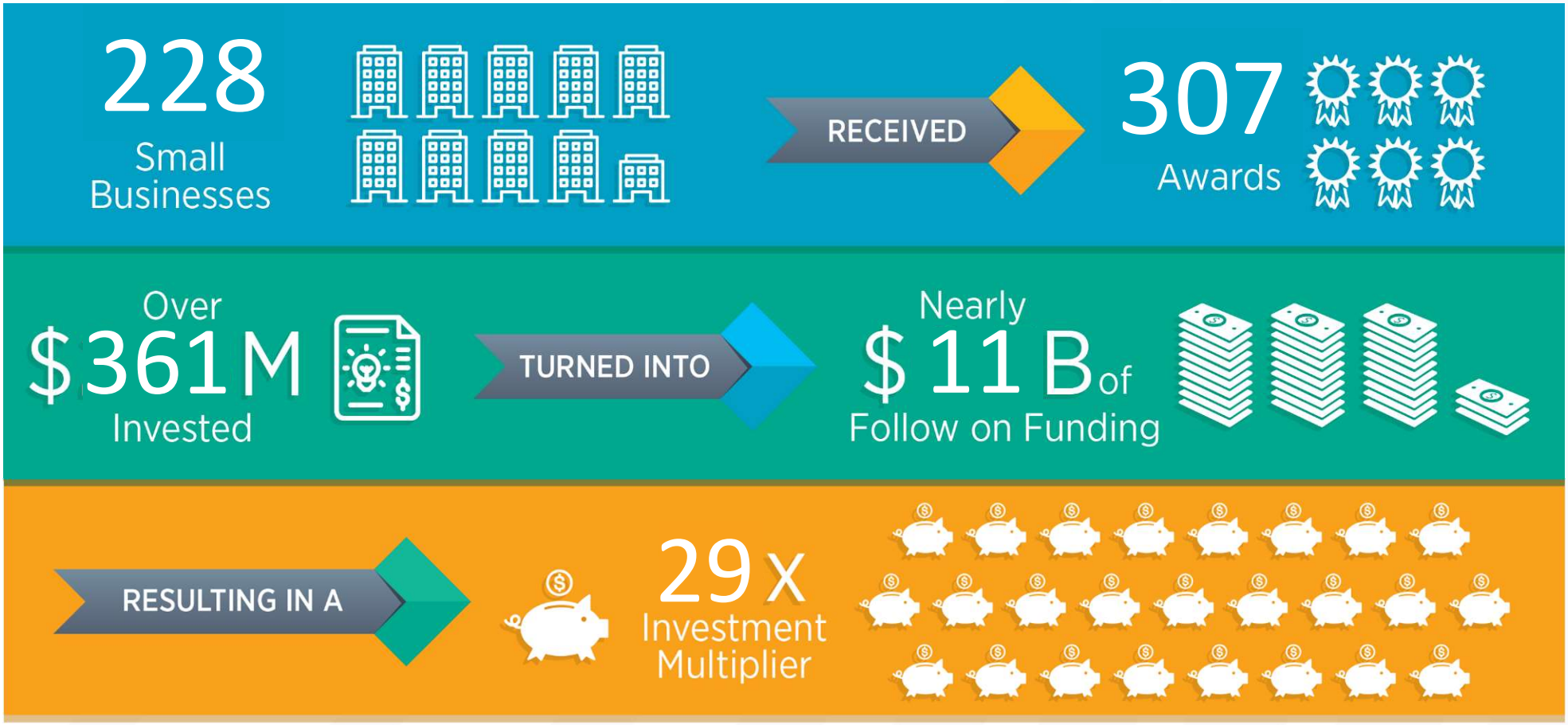




Failure:

- Creating a product to spec, on time, and on budget that no one wants.
- Finding a market need people want solved but not delivering product to spec.
- Funding redundant work at the private sector which does not help expedite a solution getting to market

Private Sector Taking Innovation to Market (2007-2021)



M&C MYPP Goals for 2025

- LCOE < $0.03/kWh in utility-scale PV systems
- 1GW/y of new U.S. PV manufacturing capacity is based on technology that was not yet commercialized in 2020
  - E.g. hybrid inverters, SiC power electronics, a new PV absorber technology, ECB IBC or MWT module architecture …
- 1 GW_{AC} of PV installed in 2025 is combined with another use, such as agriculture or building surfaces
- Solar hardware installed has at least 40% domestic value

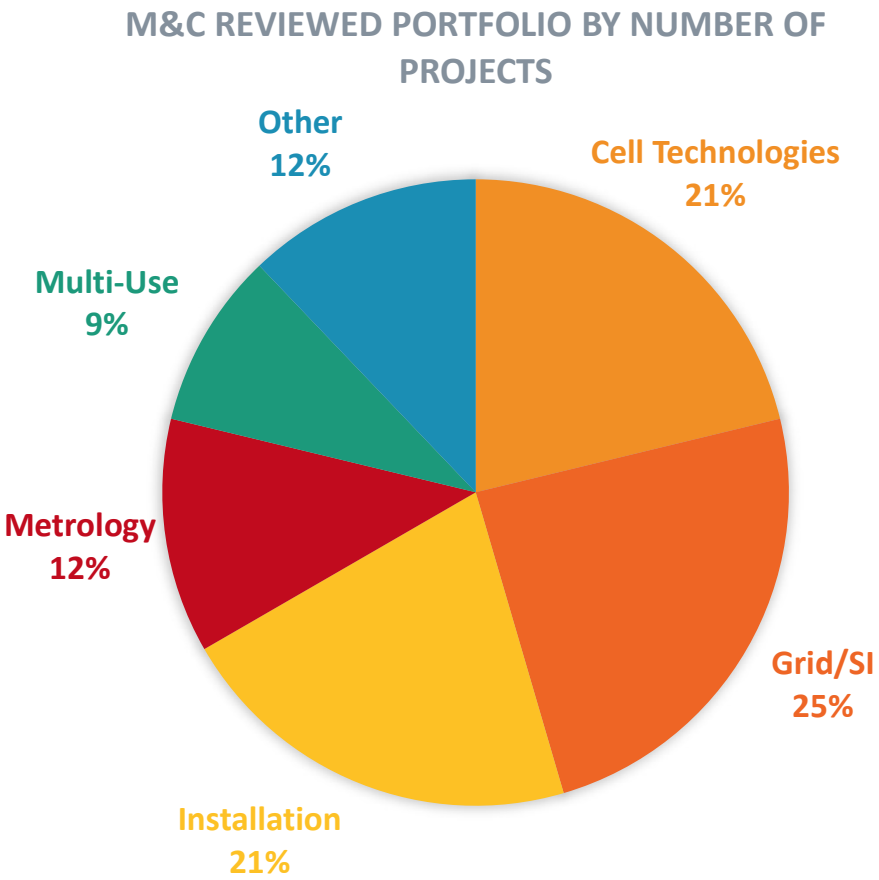
M&C Working Toward 2025

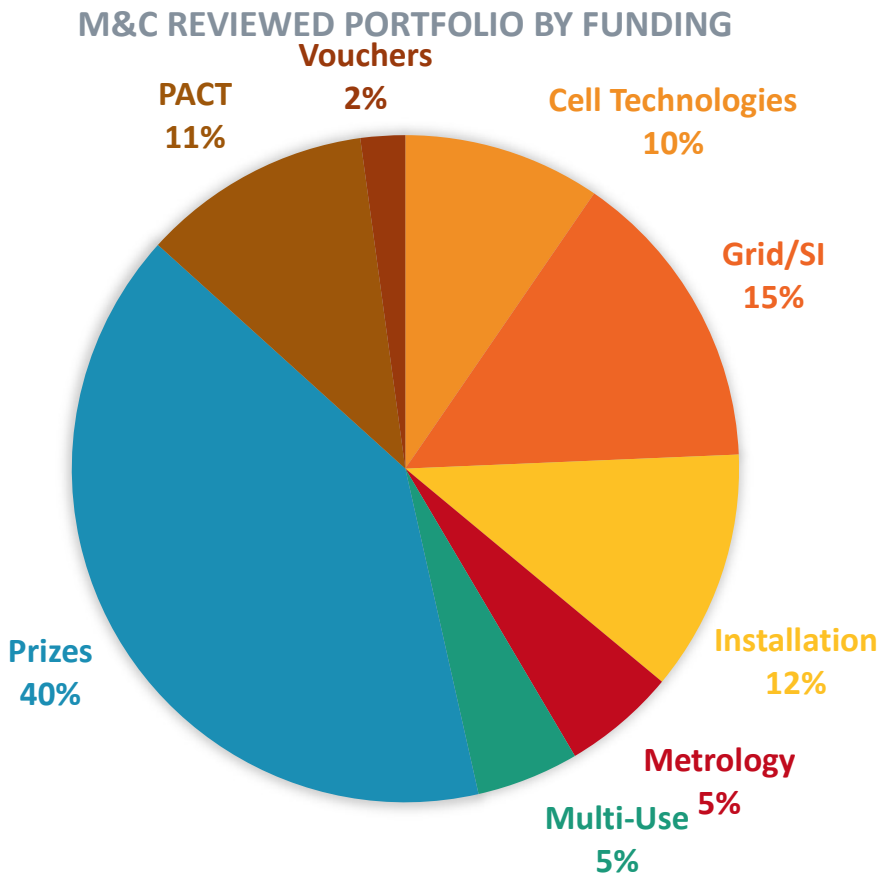
New technologies enter U.S. manufacturing

U.S. solar manufacturing capacity increases across the value chain

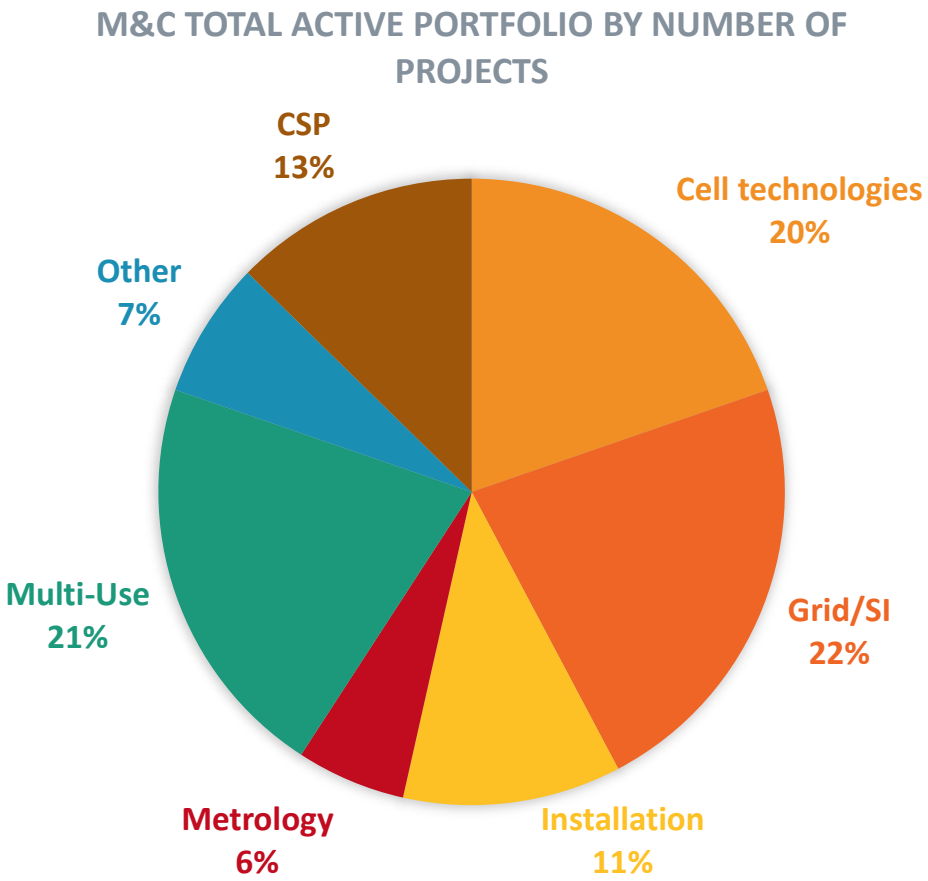
- Supporting proof of concept, pilot production, technology transfer and scale-up of new products from U.S. businesses
- Development of new technologies and business models

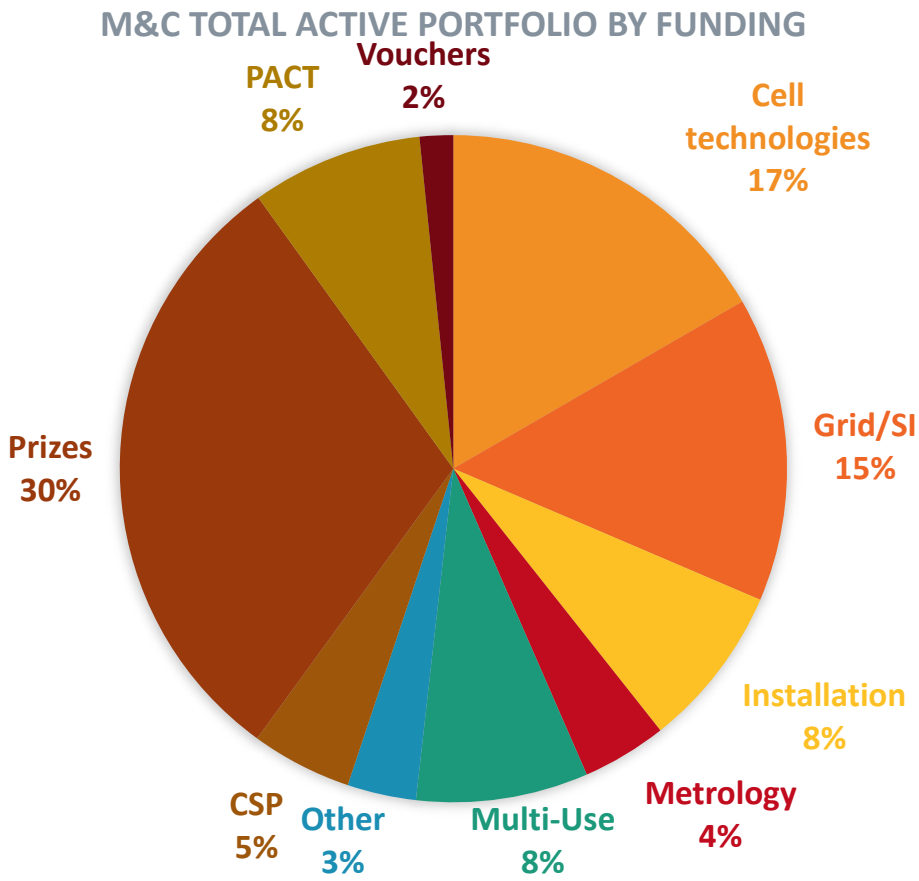
M&C Peer Reviewed Project Portfolio





M&C Total Active Project Portfolio





How can we spend money?

How can we spend money?

Prize authority

- Only winners get cash prize
- Demo day to judge competitors
- Fast program with low barrier to entry

How can we spend money?

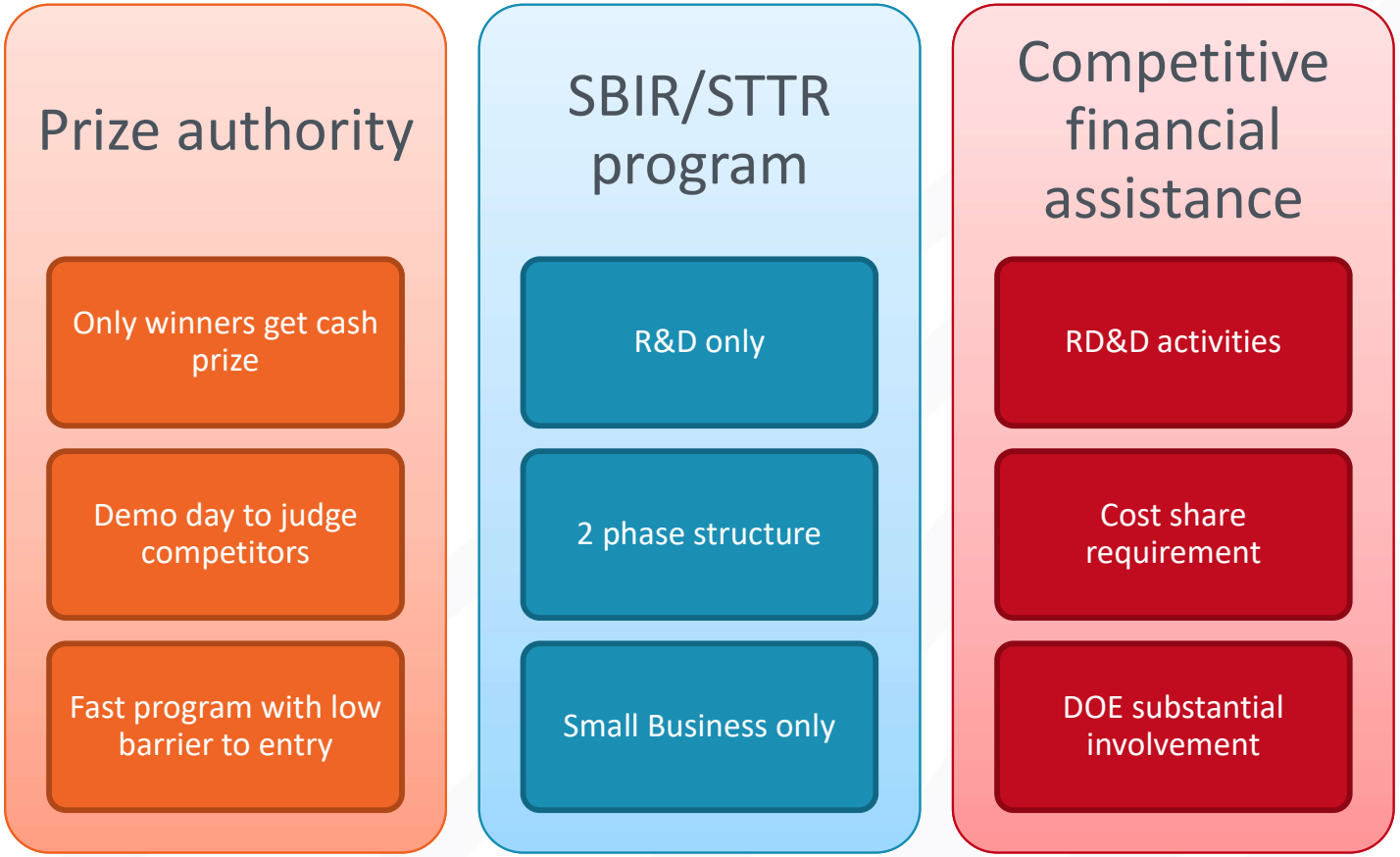
Prize authority

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SBIR/STTR program

- R&D only
- 2 phase structure
- Small Business only

How can we spend money?



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SBIR/STTR program

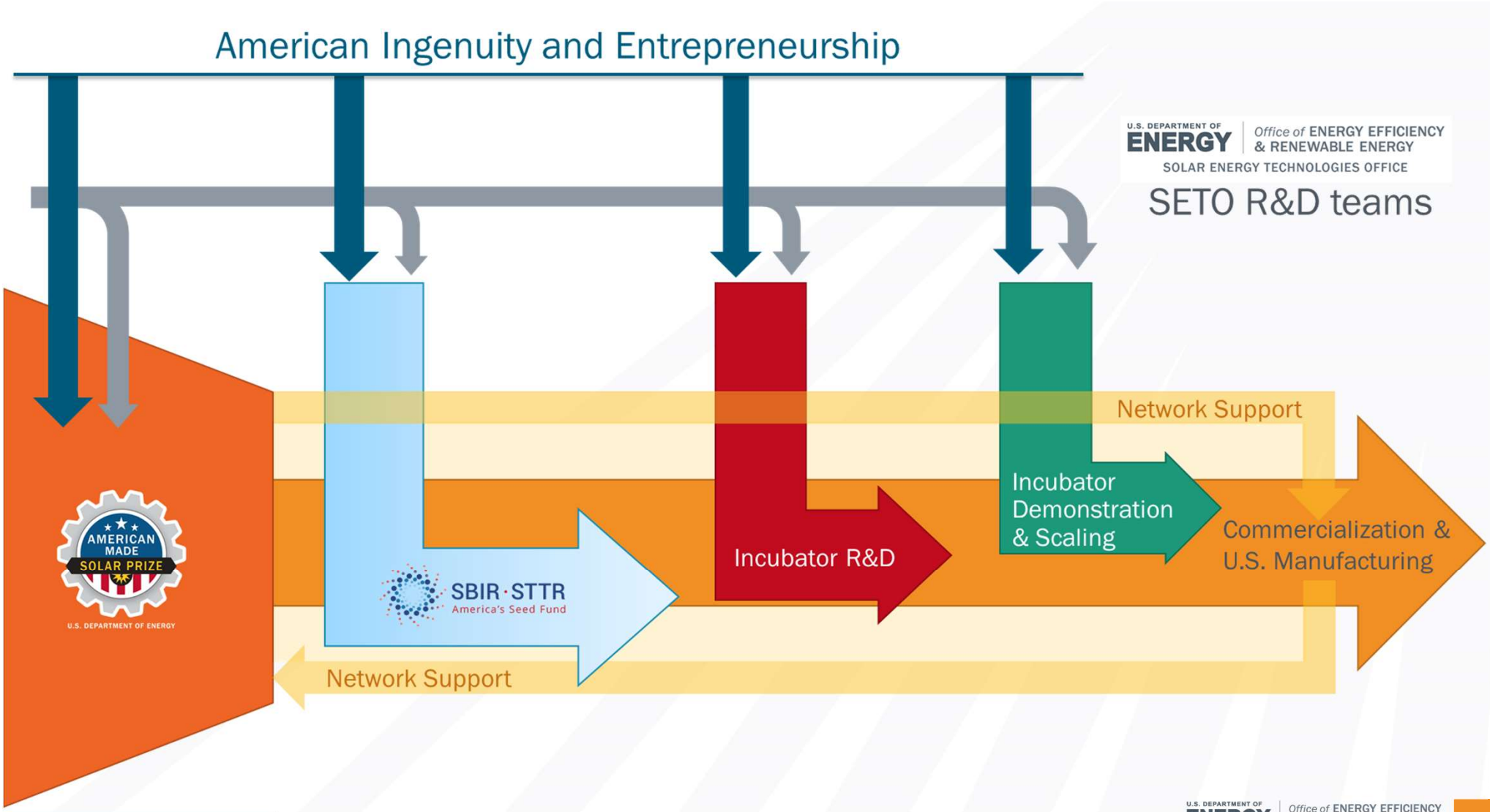
- R&D only
- 2 phase structure
- Small Business only

Competitive financial assistance

- RD&D activities
- Cost share requirement
- DOE substantial involvement

Work at National Laboratories

- TCF
- American-Made Network
- Lab voucher to awardees


American Ingenuity and Entrepreneurship
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES OFFICE
SETO R&D teams
AMERICAN MADE SOLAR PRIZE
U.S. DEPARTMENT OF ENERGY
SBIR·STTR
America's Seed Fund
Incubator R&D
Incubator Demonstration & Scaling
Commercialization & U.S. Manufacturing
Network Support
Network Support



American-Made Challenges

SOLAR PRIZE

American-Made SOLAR PRIZE

A $3 million competition designed to energize innovation in U.S. solar manufacturing.

5 Rounds initiated to date

729 submissions
from over 491 unique teams
over 5 rounds

$12 million in cash plus
$3.6 million in vouchers have already been awarded to
80 teams



Be Revolutionary

JEDI Prize Addition to Software Prize

- JEDI = Justice, Equity, Diversity, and Inclusion
- Opt-in Structure
- Describe how solution addresses solar market barriers facing underserved communities and work to substantially advance their approach toward JEDI goals as they progress through the competition
- Additional funding available at each contest (Ready!, Set!, and Go!) for successful JEDI submissions
- Specific American-Made Network support available to refine and improve JEDI concepts



$300,000 in additional prizes

	JEDI Contest Winners	Prize*
Ready!	Up to 10 Ready! semifinalists	$10,000 to $30,000 in cash
Set!	Up to 5 Set! finalists	$20,000 to $60,000 in cash
Go!	Up to 1 Go! competitor	$100,000 in cash

*Prizes are shown as funding ranges when they depend on the number of winners.

SBIR·STTR
America's Seed Fund



SUPPORTING small business SOLAR INNOVATIONS

SBIR/STTR

Small businesses

2 Phase structure

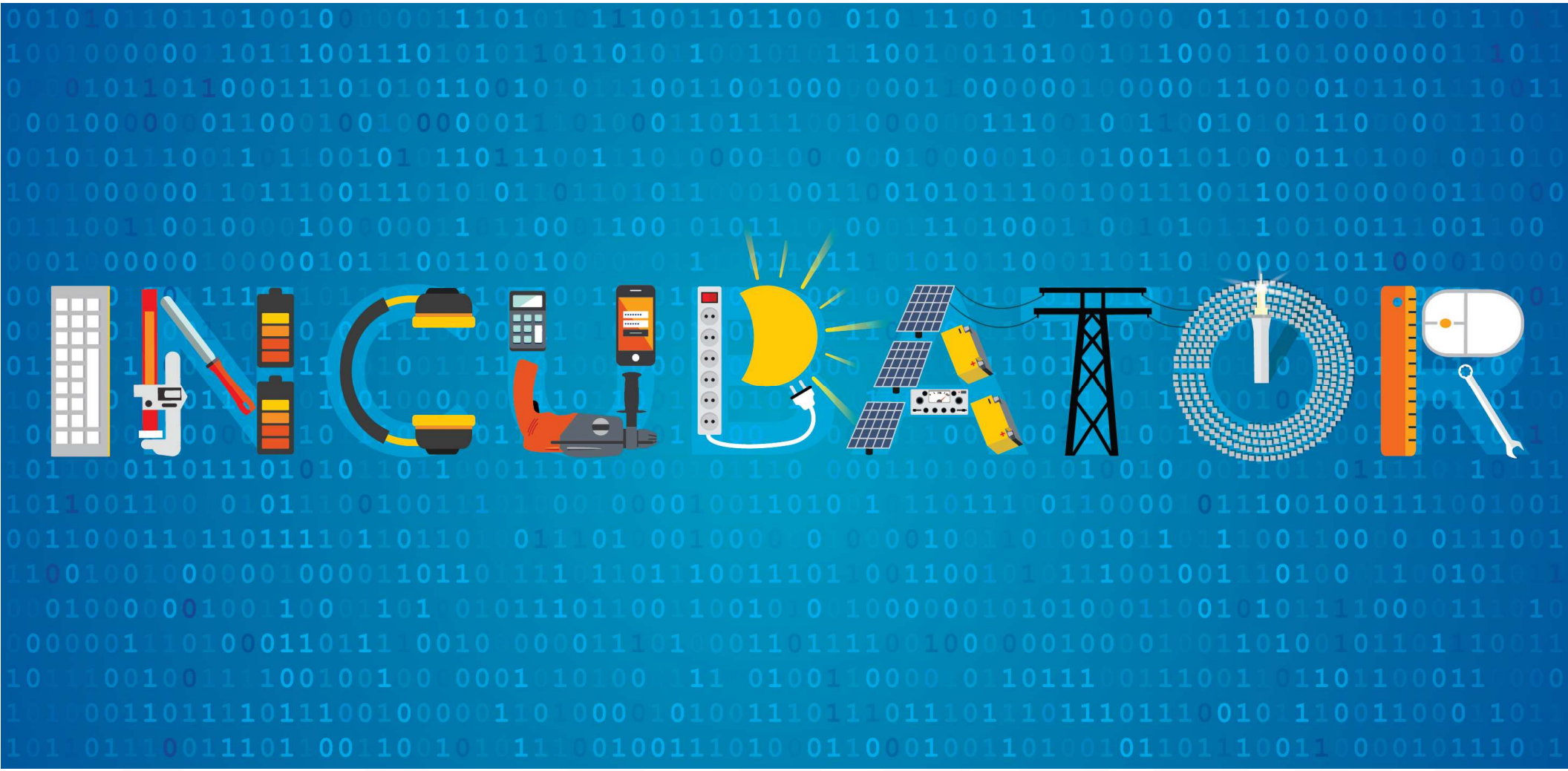
9 months (Phase I) + 2 years (Phase II)

No Cost Share

$200k (Phase I) + $1.1M (Phase II)

- Phase I is meant to conduct a feasibility study
- Phase II is meant to develop a prototype / proof of concept
- STTR encourages collaboration with research institutions
- It has a vehicle to support technology transfer (TTO) - provide funding to companies developing and commercializing a patented technology developed by a research institution

SBIR·STTR
America's Seed Fund



Innovations in Manufacturing: Hardware Incubator

For Profit Team Lead

Periods of performance 1 – 3 years

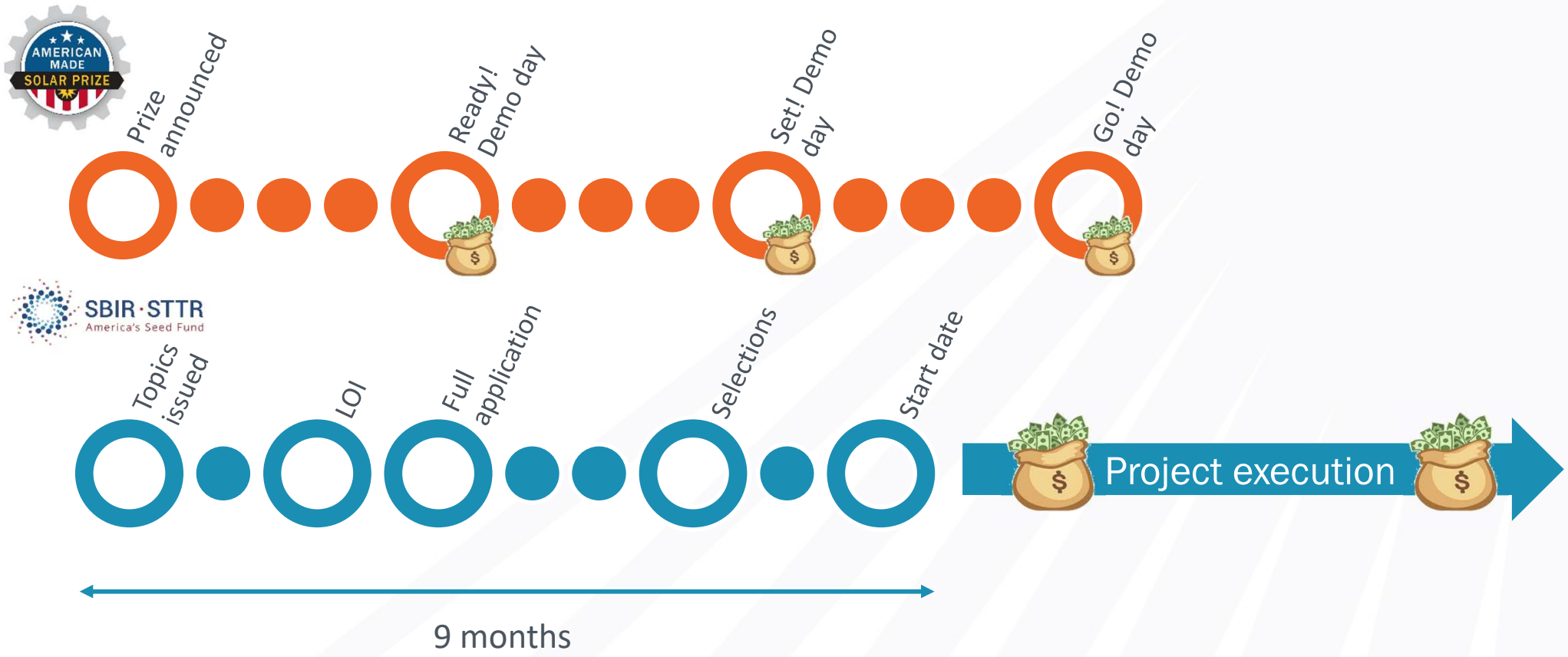
20 - 50% Cost Share

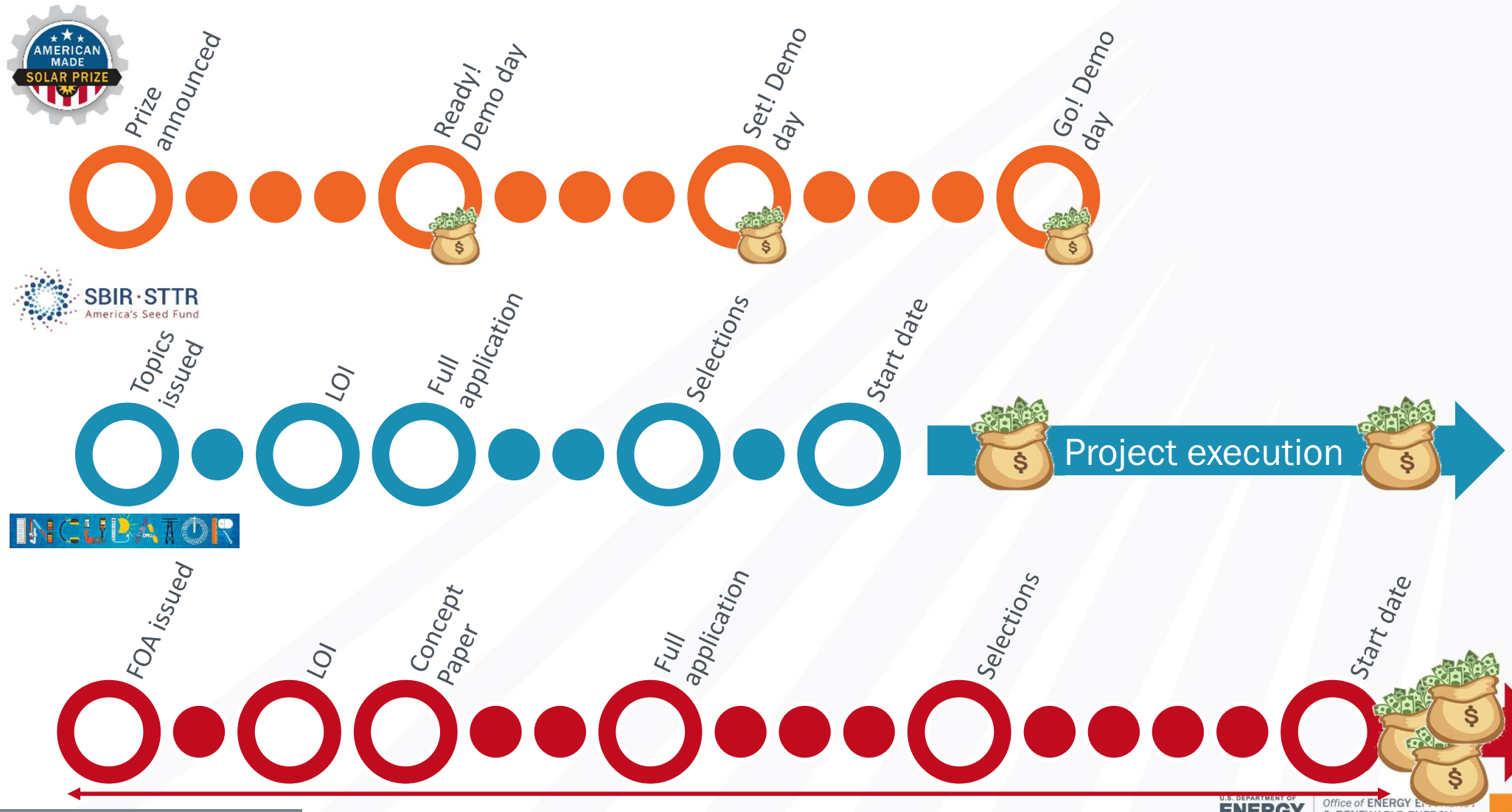
Awards range Up to $3M

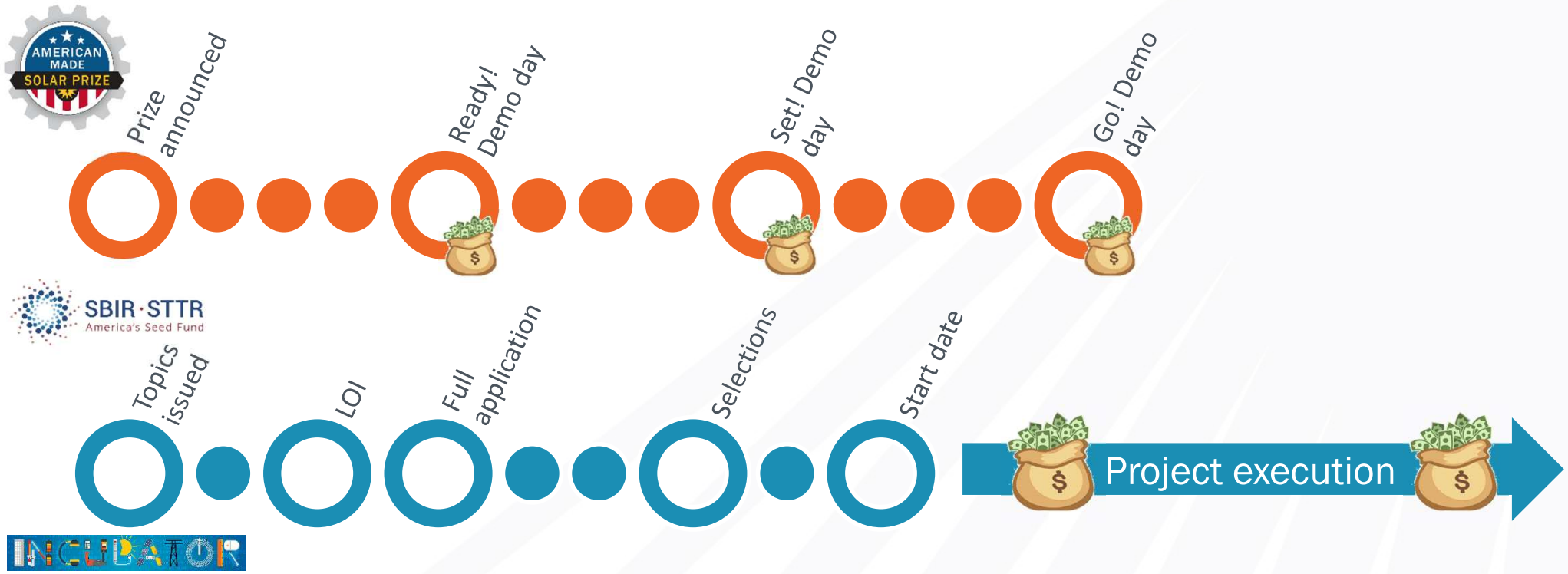
- Open topic to all hardware solutions relevant to the solar industry
- Interest in projects with potential to support a strong U.S. solar manufacturing sector and supply chain
- Focus on products with a clear pathway to reduce solar electricity costs that are too risky for private investment but have the potential for rapid commercialization
- Ideal applicant advances an existing early-stage prototype to a manufacturing and commercially relevant prototype




Prize announced
Ready! Demo day
Set! Demo day
Go! Demo day
1 year

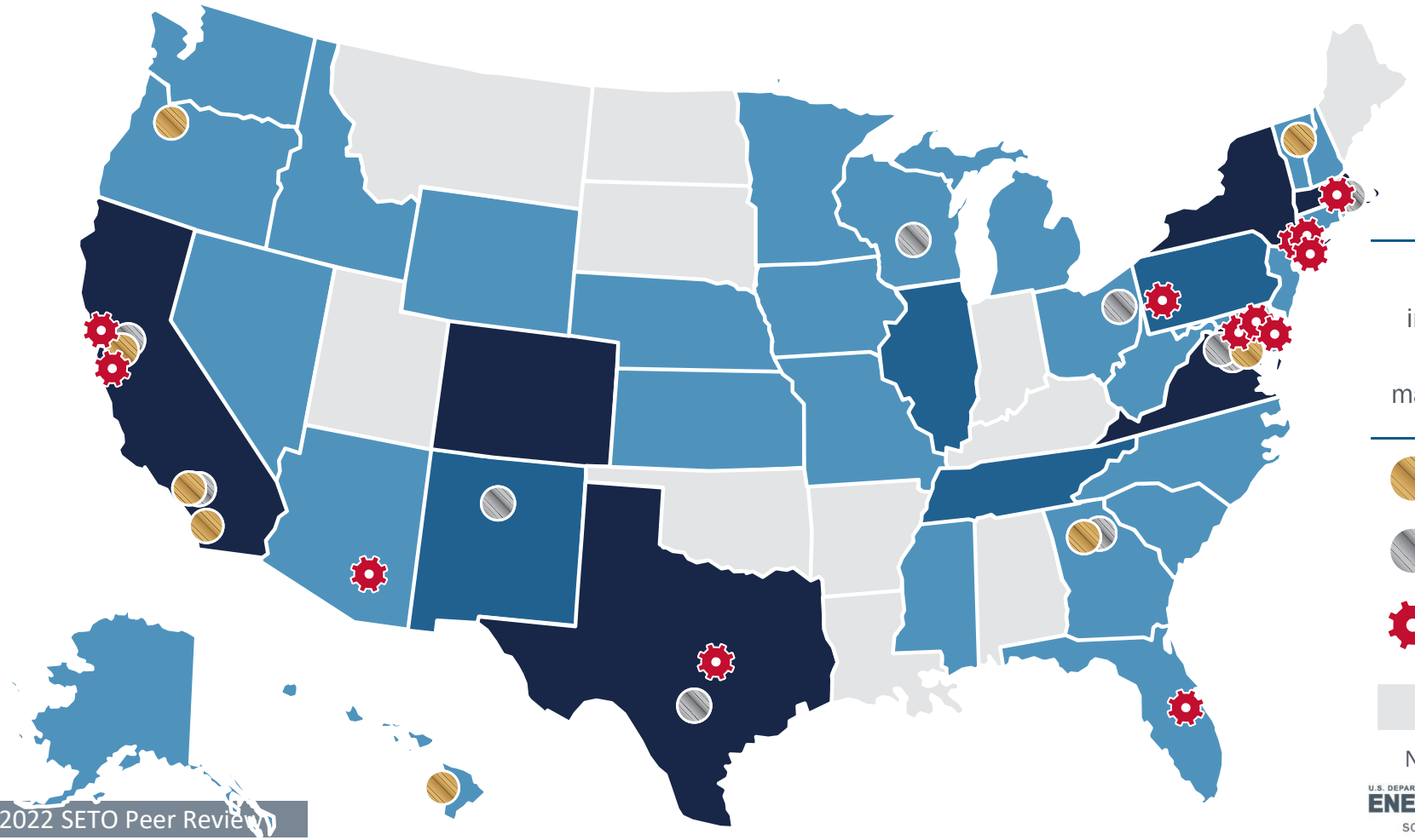

AMERICAN MADE SOLAR PRIZE
Prize announced
Ready! Demo day
Set! Demo day
Go! Demo day
SBIR·STTR America's Seed Fund
Topics issued
LOI
Full application
Selections
Start date
Project execution
9 months


AMERICAN MADE SOLAR PRIZE
Prize announced
Ready! Demo day
Set! Demo day
Go! Demo day
SBIR·STTR America's Seed Fund
Topics issued
LOI
Full application
Selections
Start date
Project execution
INCUBATOR
FOA issued
LOI
Concept Paper
Full application
Selections
Start date
16 months


AMERICAN MADE SOLAR PRIZE
Prize announced
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Project execution
INCUBATOR
FOA issued
LOI
Full application
Selections
Start date
14 months

American-Made NETWORK

Work at National Laboratories



200+ National labs, industry experts, and fabrication and manufacturing facilities

Gold Connectors

Silver Connectors

Power Connectors

None 1-5 6-9 10+

AMN Support to SBIR

Work at National Laboratories

Recruitment and Education

THE UNIVERSITY OF ARIZONA CENTER FOR INNOVATION

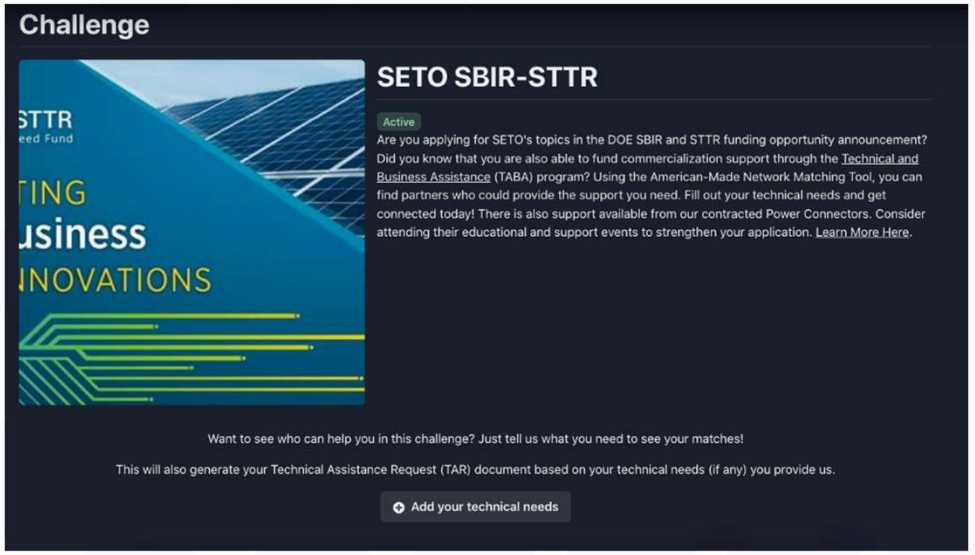
EFN Entrepreneur Futures Network

ADL MONETIZING INNOVATION

CLEAN ENERGY BUSINESS NETWORK

- Spread awareness and targeted outreach
- Application process training

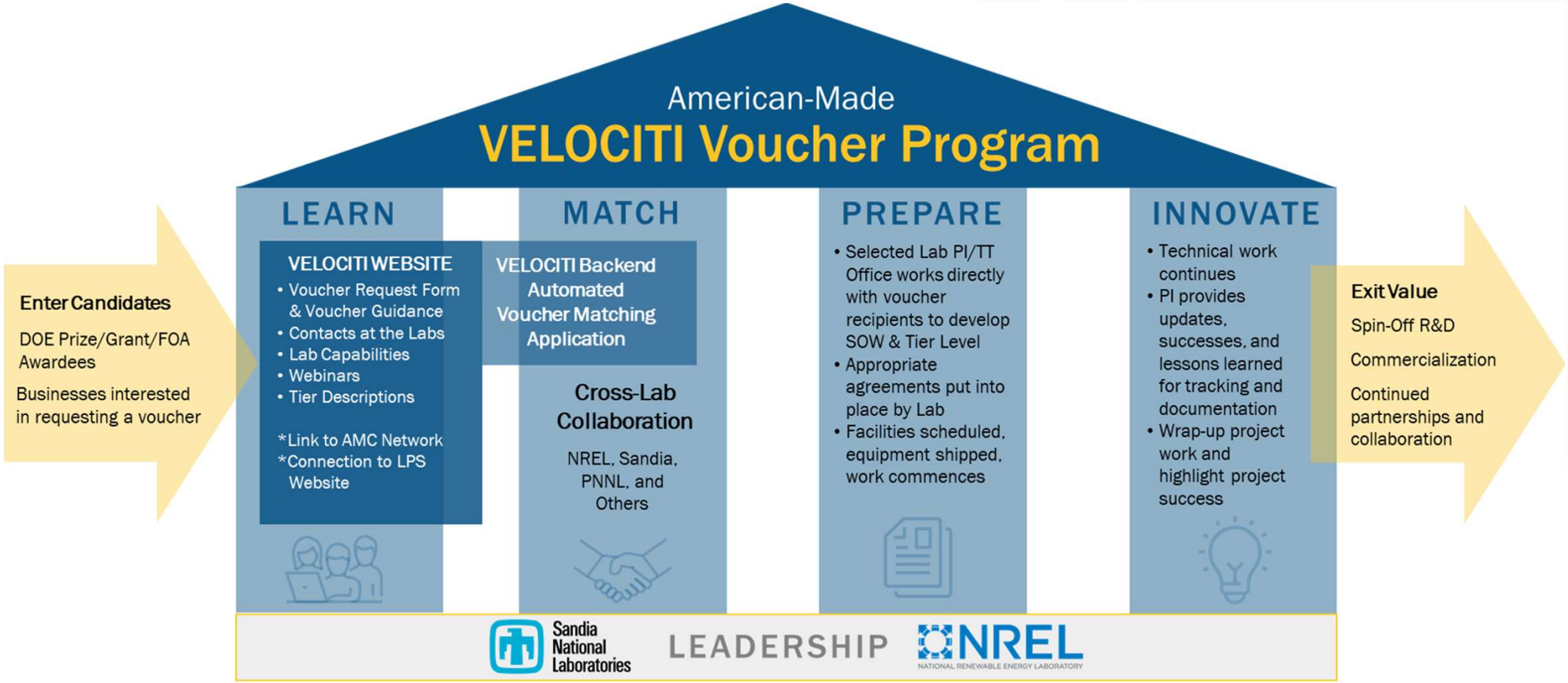
Teaming Support



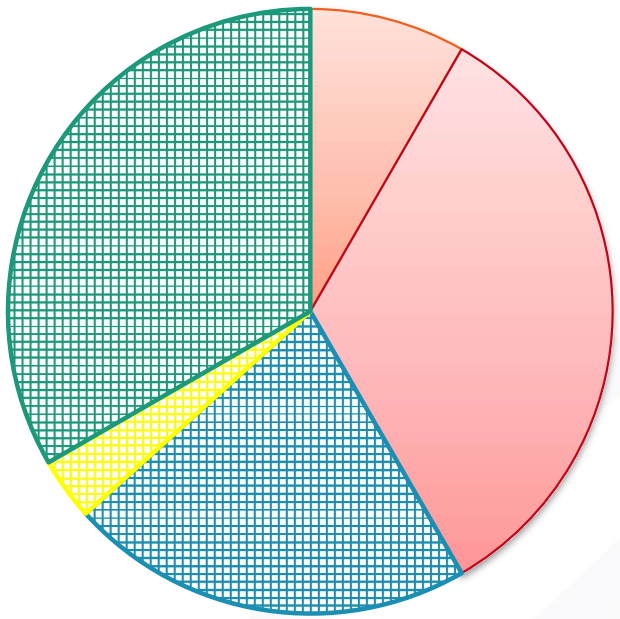
- Leverages matching platform
- SBIR applicants can find potential commercialization vendors

National Lab Vouchers - VELOCITI

Work at National Laboratories



FY21 M&C Budget



- More than 50% of the team's budget is committed to Congressionally-mandated programs
  - SBIR/STTR
  - TCF
  - Perovskite FOA
  - CdTe consortium
- Most of the remaining budget is allocated to Incubator, a program with long history of successes

Focus Area 1 – Mature Sectors

Manufacturing

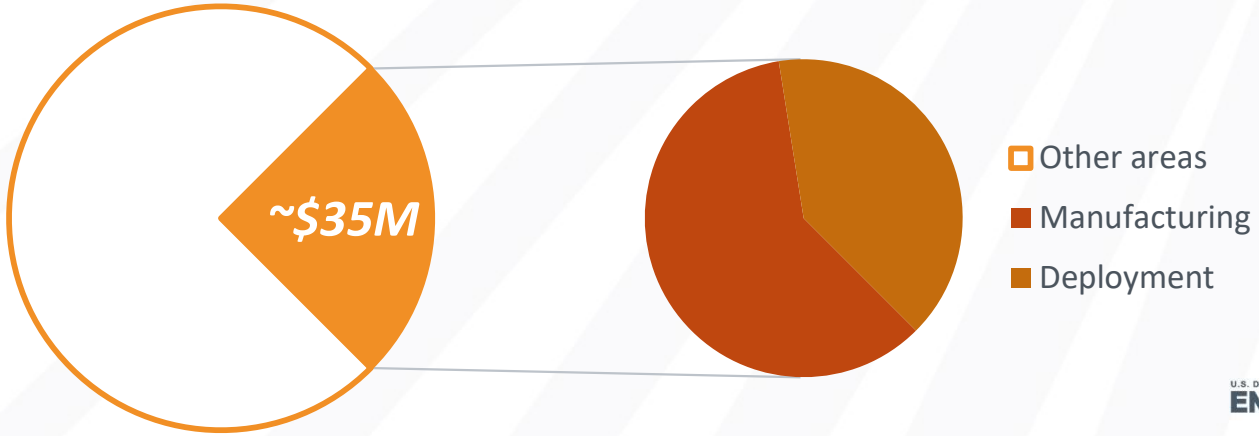
- Supply Chain
- Direct Materials
- Capital Equipment
- Production of Ingots, Cells, Modules, Electrical BOS, Structural BOS

Deployment

- Project Design, Development, and Installation
- Sales
- Distribution
- Financial Services

Operation

- Controls and Market Participation
- Operations & Maintenance
- Financial asset management
- End of Life



Mature Sector Portfolio Highlights



PV Supply Chain & Manufacturing



Balance of System



Installation Automation

PV Supply Chain

Halo Industries

LeadingEdge Equipment Technologies

Wafering



osazda ENERGY

BERT THIN FILMS LLC

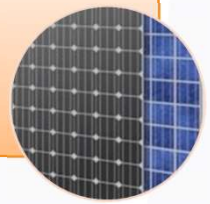
Silicon Valley Materials Technology SVMT LLC

Metallization



SWIFTCOAT

Coatings



PV Manufacturing

= prize winner

SBIR·STTR America's Seed Fund

INCUBATOR

SILFAB SOLAR (*)

Module Manufacturing



Sinton instruments

SciONPLASMA

Tau Science Built for Solar

Equipment Development



nexTC

TOLEDO SOLAR

CdTe PV Accelerator

CdTe Manufacturing



(*) under negotiation

Balance of System

= prize winner

SBIR·STTR America's Seed Fund

INCUBATOR

- Residential
  - Phase3 Photovoltaics
  - Span
- Commercial
  - Quest Renewables
  - Tectonicus Constructs
- Utility
  - Atonometrics
  - Sandia National Lab & Array Technologies (TCF)







Installation Automation

terabase

- Field Factory for Cost Reduction and Deployment Acceleration of PV Power Plants
- Autonomous Control System for PV Table Delivery and Placement

re² ROBOTICS

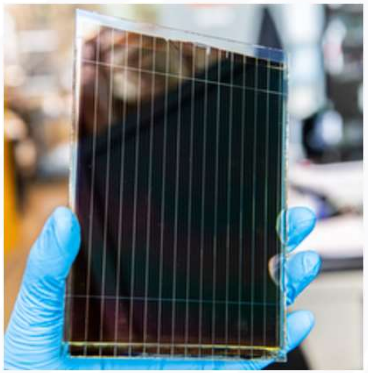
- Outdoor Autonomous Manipulation of Photovoltaic Panels (O-AMPP)



Focus Area 2 – Emerging Technologies

Perovskite Photovoltaics and Hybrid Tandems

- Key Challenge: Bankability (reliant on verified durability, manufacturability)
- Joint Area with PV Subprogram
- Portfolio: Approximately ***$90M federal***





Wide Band-Gap Power Electronics (SiC, GaN)

- Key Challenge: Product fit, cost-competitiveness
- Joint Area with SI Subprogram
- Portfolio: Approximately ***$10M federal***

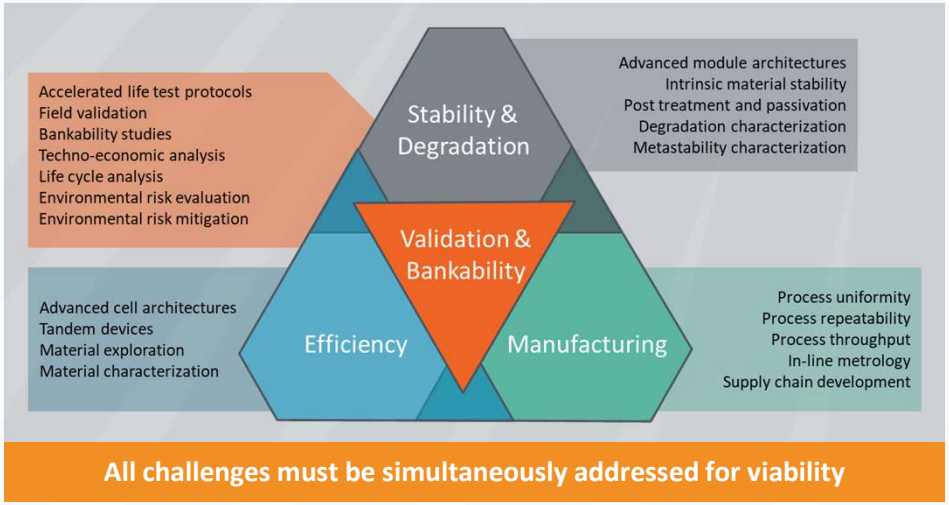




How Do We Develop Strategies and Programs?

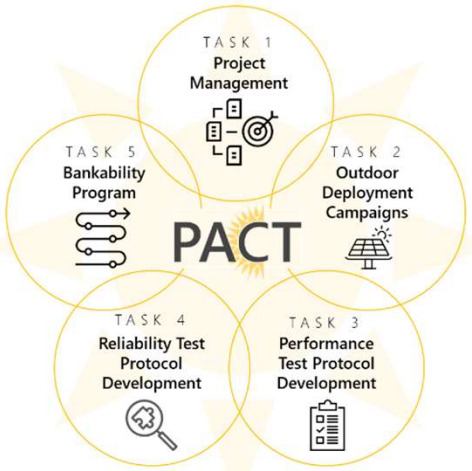
- **Motivation:** Perovskites show potential for high efficiency; low production cost, low CapEx
- **Objectives:** Substantial market entry in <10 years (multiple entities, MMW-GW/yr)
- **Requirements:** Competitive, validated performance:
  - Power density [W/m^2]
  - Energy yield [kWh/kW-year]
  - Production cost [$/W]
- **Key Challenge Areas**
- **Program Development**
  - SETO PVSK FOA - $40M selected (22 projects)
  - FY21 PVRD FOA - $1M selected (4 projects)
  - FY22-FY24 National Labs programs launched

→ ***Based on start date, few of these are being individually reviewed***



Validation & Bankability: How Do We Build Confidence…

About Where We Are…







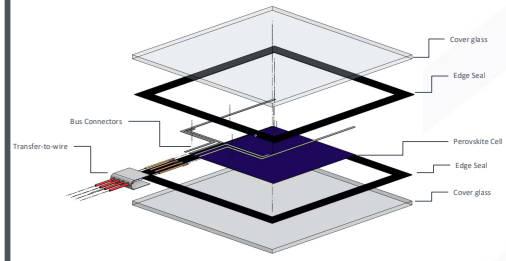


Fig.1. Exploded view of proposed packaging structure

About Where We're Going…

Perovskite Performance Targets

- Establish common objectives
- Align community efforts
- Provide evidence of readiness for initial production

→ ***Under revision following RFI in fall 2021***

Configuration	Aperture Area PCE[1]	Total Module Area[2]	Durability	Sample Population Requirements
Single Junction	18% PCE	>=500 cm^2 with at least 4 inter-connected cells	Pass IEC 61215 MQT 10, 11, and 21 and ISOS-L-2 at specified durations with <10% relative performance loss per test[3] 6 months continuous outdoor testing with <3% relative degradation overall and <1% degradation in the final 3-month span[4]	>1kW total, at least 20 modules for outdoor testing[5]
PVSK-only Tandems	24% PCE			
Hybrid Tandems	27% PCE			

Perovskite Portfolio Selections

= prize winner

EMC Energy Materials Corporation HIGH SPEED, ROLL-TO-ROLL PRODUCTION OF DURABLE, LOW-COST, BIFACIAL PEROVSKITE PHOTOVOLTAIC MODULES	First Solar HIGH –THROUGHPUT AND –YIELD PROCESS USING IN-LINE METROLOGY FOR SHEET-TO-SHEET MANUFACTURING OF PEROVSKITE MODULES
Tandem PV FULL SCALE PEROVSKITE/ SILICON TANDEM MODULES	SwiftSolar HIGH-THROUGHPUT VAPOR DEPOSITION FOR PEROVSKITE-PEROVSKITE TANDEM MODULES

Variety of industry approaches: Wet vs dry processing, single junction, 2T and 4T tandems

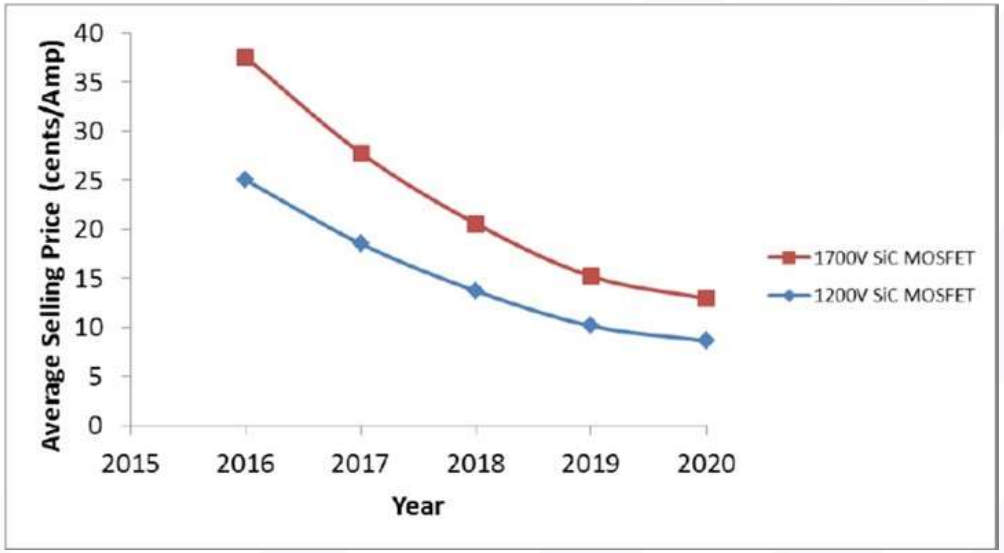
Perovskite Portfolio Selections

Advanced Devices and Tandems	NREL NATIONAL RENEWABLE ENERGY LABORATORY	ADVANCED PEROVSKITE CELLS AND MODULES; TANDEM PHOTOVOLTAIC DEVICES; FROM DEVICES TO ATOMS: ASSESSING PEROVSKITE STABILITY AND METASTABILITY BY SPATIALLY RESOLVED IN-SITU AND TARGETED EX-SITU
	THE UNIVERSITY OF TOLEDO	TOWARD LOW-COST, EFFICIENT AND STABLE PEROVSKITE THIN-FILM MODULES
Fabrication and Stabilization	Stanford University	OPEN-AIR MANUFACTURING OF EFFICIENT LARGE-AREA PEROVSKITE SOLAR CELLS TO MEET STABILITY AND COST TARGETS
	THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL	STABILIZING FORMAMIDINIUM-CESIUM MIXED CATION PEROVSKITES
Metrology and Characterization	University of Colorado Boulder	STUDYING PEROVSKITE SOLAR CELLS IN REVERSE BIAS TO ACCELERATE AND INVESTIGATE DEGRADATION DUE TO ELECTROCHEMISTRY AND HALOGEN MIGRATION
	SLAC NATIONAL ACCELERATOR LABORATORY	TOTAL CHARACTERIZATION OF PEROVSKITE FILMS FOR ENHANCED STABILITY
	UNIVERSITY of WASHINGTON	FORECASTING PEROVSKITE PHOTOVOLTAIC DEVICE PERFORMANCE USING DARK-FIELD IMAGING AND MACHINE LEARNING

Wide-Bandgap Power Electronics – Motivation

Next-generation inverters/converters for solar applications and hybrid solar systems utilizing SiC and GaN modules

- Accelerated WBG-device market growth and dropping chip prices, driven by the expanding electric vehicle industry
- Leverage prior investments from AMO, VTO and others



https://www.nist.gov/system/files/documents/pml/high_megawatt/Banerjee-APPROVED.pdf

Opportunity to use WBG chips in **power-electronics components for the solar** industry in a **cost-competitive way** compared to incumbent technologies.

The United States is a pre-eminent supplier of high-quality SiC wafers and chips making a **compelling case for domestic manufacturing**.

Wide-Bandgap Power Electronics – Focus and Goals

- Develop the next generation of power-electronic devices leveraging the **benefits of wide-band-gap materials** (like SiC and GaN)
- Extend the state of the art in areas such as:
  - innovative inverter/converter **designs and topologies**,
  - **transformer-less** designs and **planar magnetics**,
  - **faster switching** frequency applications,
  - **high-power** applications,
  - **high-voltage** applications,
  - **design and build processes**.
- Create **cost**-competitive, high-**performance**, high-**reliability** alternatives to silicon-based equipment
- Combine technical innovation with promoting the case for **domestic manufacturing** of equipment (e.g. inverters)

Wide-Bandgap Power Electronics – Portfolio Selections

= prize winner

SBIR·STTR America's Seed Fund

INCUBATOR

Component Manufacturing

Halo Industries

Advanced silicon carbide wafer manufacturing for low-cost, high-efficiency power electronics in solar applications – **Halo Industries, Inc.** (INCUBATOR FY19)

Advanced Inverters

BREK ELECTRONICS

250 kW solar string inverter using silicon carbide (SiC) modular architecture and grid support functionality – **BREK Electronics Corp.** (SBIR/STTR FY19)

YASKAWA SOLECTRIA SOLAR

The BREKTRIA 500: A breakthrough in technology and power density for an advanced 500kW utility-scale string inverter – **Solectria Renewables, LLC** (INCUBATOR FY20)

IMAGEN

Compact, high-power, direct-medium-voltage solar PV inverter – **Imagen Energy, LLC*** (INCUBATOR FY21)

Multi-Port Devices for PV + Storage

A modular and flexible multi-terminal power converter with grid-forming capability for integrated PV solar and battery energy storage – **General Electric Company** (INCUBATOR FY21)

TOSHIBA

TOSHIBA INTERNATIONAL CORPORATION

Commercialization of M4 inverter: Modular, multifunction, multiport and medium voltage utility-scale SiC PV + storage inverter – **Toshiba International Corporation*** (INCUBATOR FY21)

** Selected – Currently under negotiation*

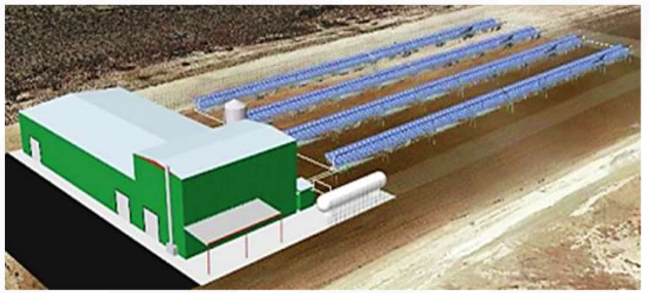
Focus Area 3—Emerging Sectors

- Application-specific/multi-use integration of solar
  - **BIPV** — Building Integrated Photovoltaics
  - **Agrivoltaics** — Agricultural Photovoltaics
  - **Floatovoltaics** — Floating Photovoltaics
  - **Concentrating Solar Power** — Industrial Process Heat









Building Integrated Photovoltaics

= prize winner

SBIR·STTR America's Seed Fund

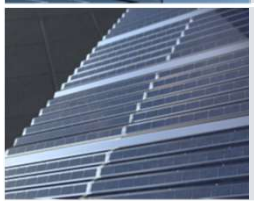
INCUBATOR



Windows



Facades



Roofing



Aesthetic

Building Integrated PV

- Toledo Solar (FY20)
- *Next Energy (FY18)*
- ***Nanoflex (FY19)***
- Toledo Solar (SBIR FY20)
- Enviromation (SBIR FY21)
- Otherlab (SBIR FY21)

Aesthetic PV:

- Sistine Solar (*FY15*, FY21)
- Asoleyo Solar (AMSP R2; SBIR FY21)
- r&d lab (AMSP R4)

Training/Education

- NREL/Architectural Solar Association
  - Jointly with SAIS & BTO
  - Selected, not finalized

Programs:

- Topic Areas within SBIR
- Incubator RFI
- BIPV RFI (Planned, Joint with BTO)

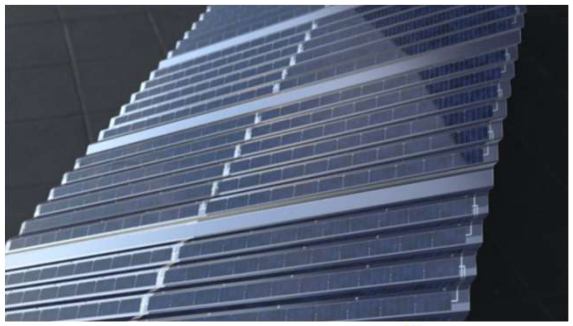
Active program area for SETO
Total projects in last 5 years ~$15M

BIPV – Technology Examples

= prize winner

SBIR·STTR America's Seed Fund

INCUBATOR

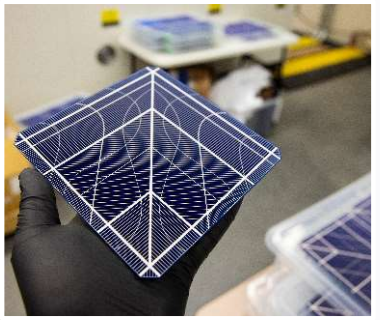


OtherLab



Sistine Solar

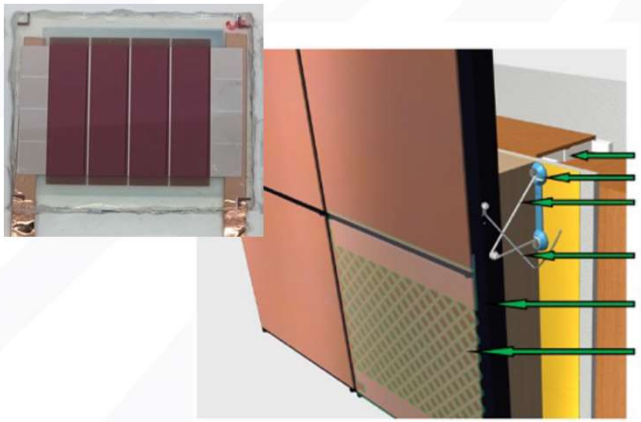




Asoleyo



Toledo Solar

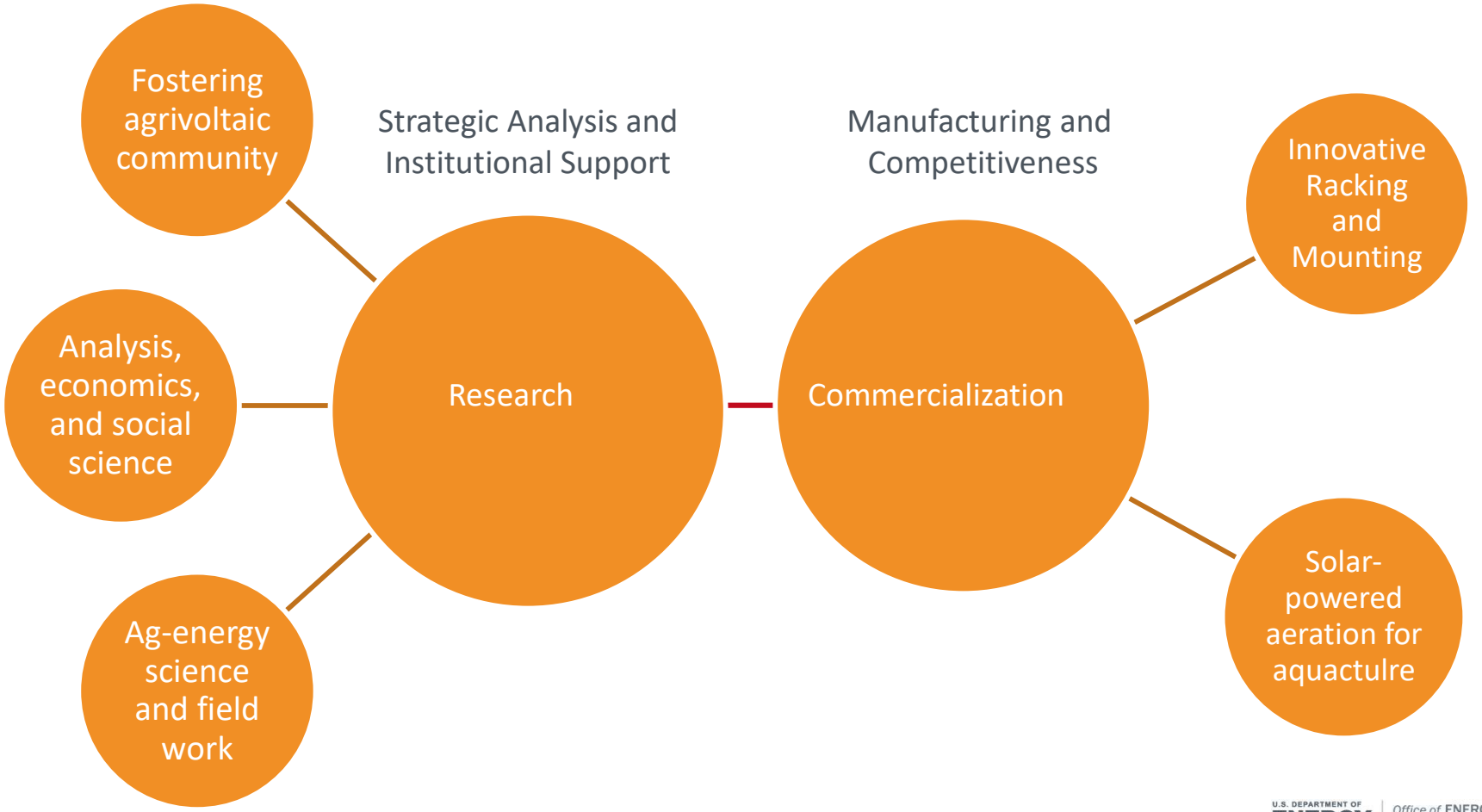


NanoFlex



r&d lab

SETO Research and Commercialization Activities in Agrivoltaics



Agrivoltaics Example

- **FarmAfield – SBIR Phase-II project integrates PV with livestock feeding structures improves quality *and* LCOE**





- **Their SBIR Phase-I floating solar aeration project is to improve water and fish quality in aquaculture**

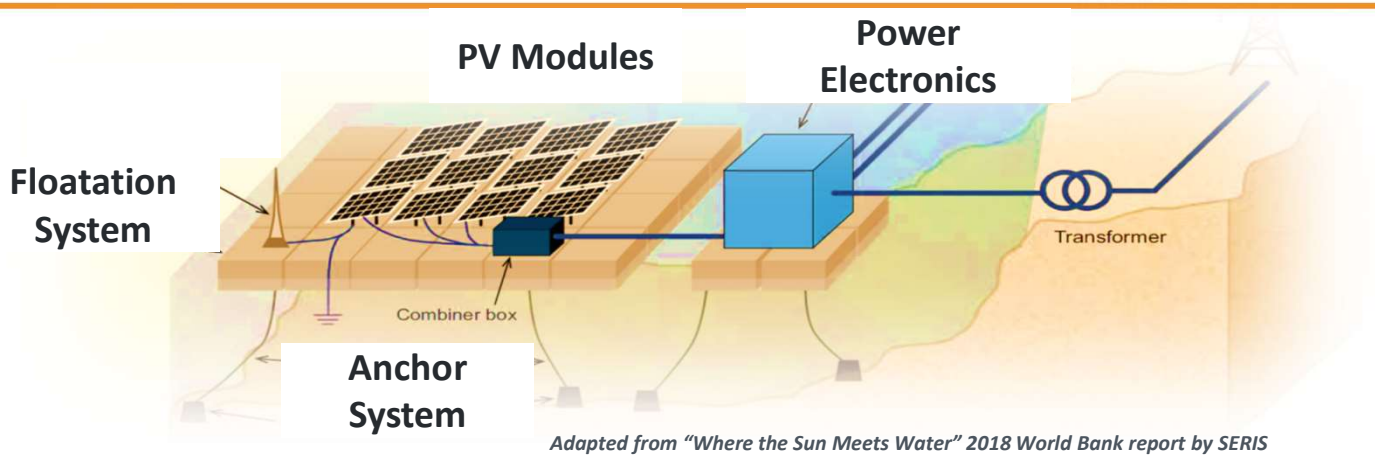
Agrivoltaics– SBIR New Cohort

= prize winner

- Solar racking/mounting design optimized for co-location:
  - Blue Rock Solutions – suspended solar racking ($200,000, 1Y, FY2021 SBIR)
  - Rute Foundation Systems – cable stayed solar racking ($199,999, 1Y, FY2021 SBIR)
  - Taka Solar Corporation – tube-based photovoltaic system ($206,300, 1Y, FY2021 SBIR)
  - TrackerSled – modular solar trackers for rural application ($195,382, 1Y, FY2021 SBIR)



Floating Solar Photovoltaics



Adapted from "Where the Sun Meets Water" 2018 World Bank report by SERIS

- "Floatovoltaics" uses solar photovoltaic (PV) modules on flotation systems to convert sunlight into electricity on bodies of water
- Strategies to float, anchor, rack the PV and waterproof the systems distinguish competitors
- Potentially lower temperature operation can boost efficiency
- Durability to corrosion, biofouling, etc. can be a challenge

Floatovoltaic Advantages





- Floating solar installations make use of water resources to deploy solar, often where large areas of open land are unavailable
- Floatovoltics can bring solar electricity to industry-related bodies of water, such as municipal wastewater, that also face land constraints
- NREL identified >24,000 floatovoltaic-suitable US artificial water resources

SETO Funded Floating Solar PV projects



- **Accusolar:** new racking system and advanced manufacturing (selected for $1.5M Federal/ $7M cost share cooperative agreement, 2 Y, FY21)
- **Dissigno International**: new float and racking system design (selected for $3M, 1Y, FY 2021)
- **Dissigno International**: aeration for integration into existing large-scale floating solar energy projects deployed on wastewater ($199,438, 1Y, FY2021 SBIR)
- **FarmaField Labs**: integrates solar into existing floating pond aeration to improve fishery production ($0.2M, 1Y, FY21 SBIR)
- **Floating Island International**: solar and nanobubble aeration integrated with natural appearing floating island platform for improved water quality ($0.2M, 1Y, FY2021 SBIR)
- **Hawaii Fish Company**: efficient, floating water aeration system powered by solar and wind with storage for fish farmers ($0.21M, 1Y, FY2021 SBIR)
- **Epsilon Innovation Group**: self-sufficient floating solar aeration system coupled with energy storage to improve water quality and protect underwater organisms and habitats. ($0.2M, 1Y, FY21 SBIR)
- **University of Central Florida:** Study of the environmental impacts and performance of FPV on human-made bodies of water ($0.85M, 3 years, FY18 SAIS)
- **INL/NREL:** Study of the economic and regulatory barriers to FPV deployment on hydropower dams, reservoirs, and estuaries ($2.5M, 3 years, FY21 SAIS)
- M&C partners outside SETO with WPTO and other agencies to facilitate floatovoltaic development

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SOLAR ENERGY TECHNOLOGIES OFFICE

2022 SETO PEER REVIEW

Thank You

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SOLAR ENERGY TECHNOLOGIES OFFICE

2022 SETO PEER REVIEW

SETO Photovoltaics R&D

Lenny Tinker

PV R&D Program Manager

Photovoltaics Team


Lenny Tinker


Brion Bob


Tassos Golnas


Susan Huang


Inna Kozinsky


Peter Lobaccaro


Marie Mapes


Jeremey Mikrut


Emanuele Pecora


Timothy Siegler


Nancy Truong


Allan Ward


David Wilt

Decarbonizing the Electricity and Energy Sectors

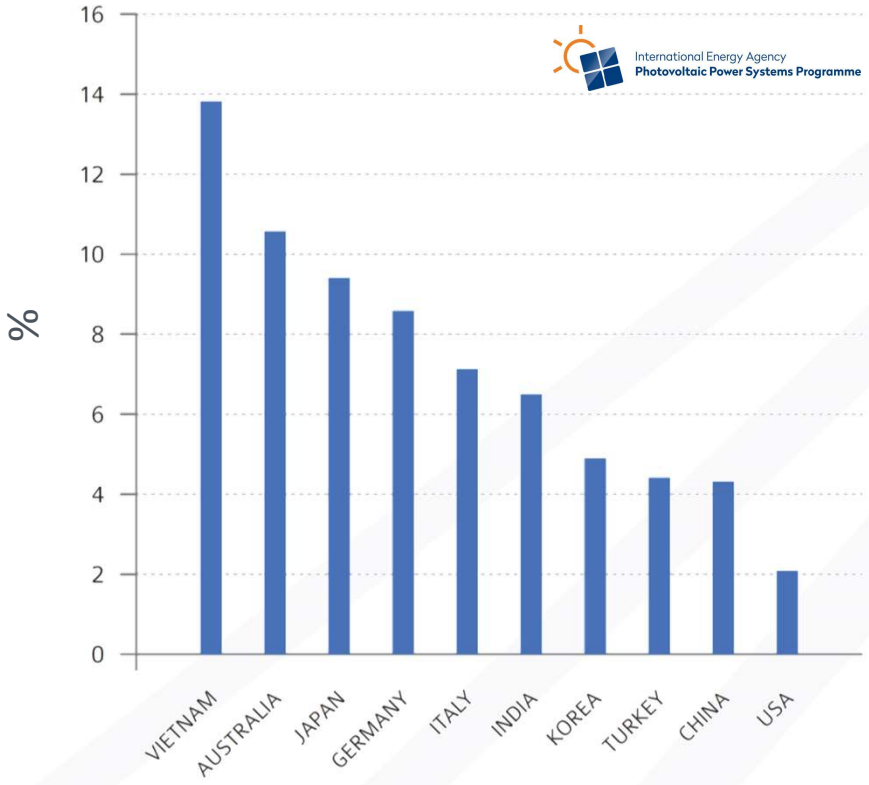
The US is targeting a carbon-free electricity sector by 2035 and 100% clean energy economy with net-zero emissions by 2050

- In a fully decarbonized grid, predictions indicate that **30-50% of U.S. electricity generation would come from solar**
- To meet the 2035 goal, we need to deploy solar at **two to five times the current rate**

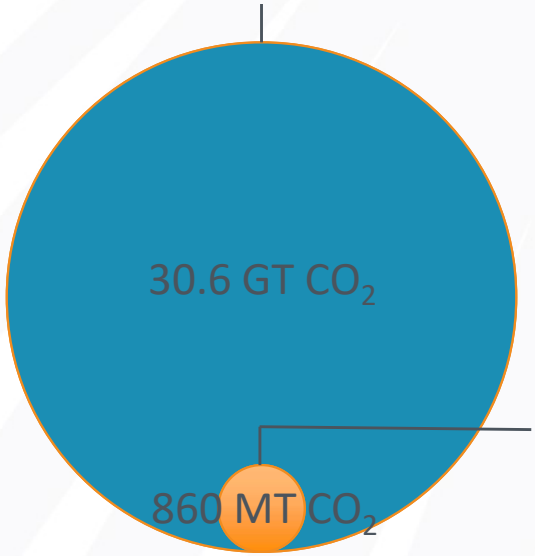


We're Making Progress

CO_2 emissions avoided by PV as a percentage of total emissions



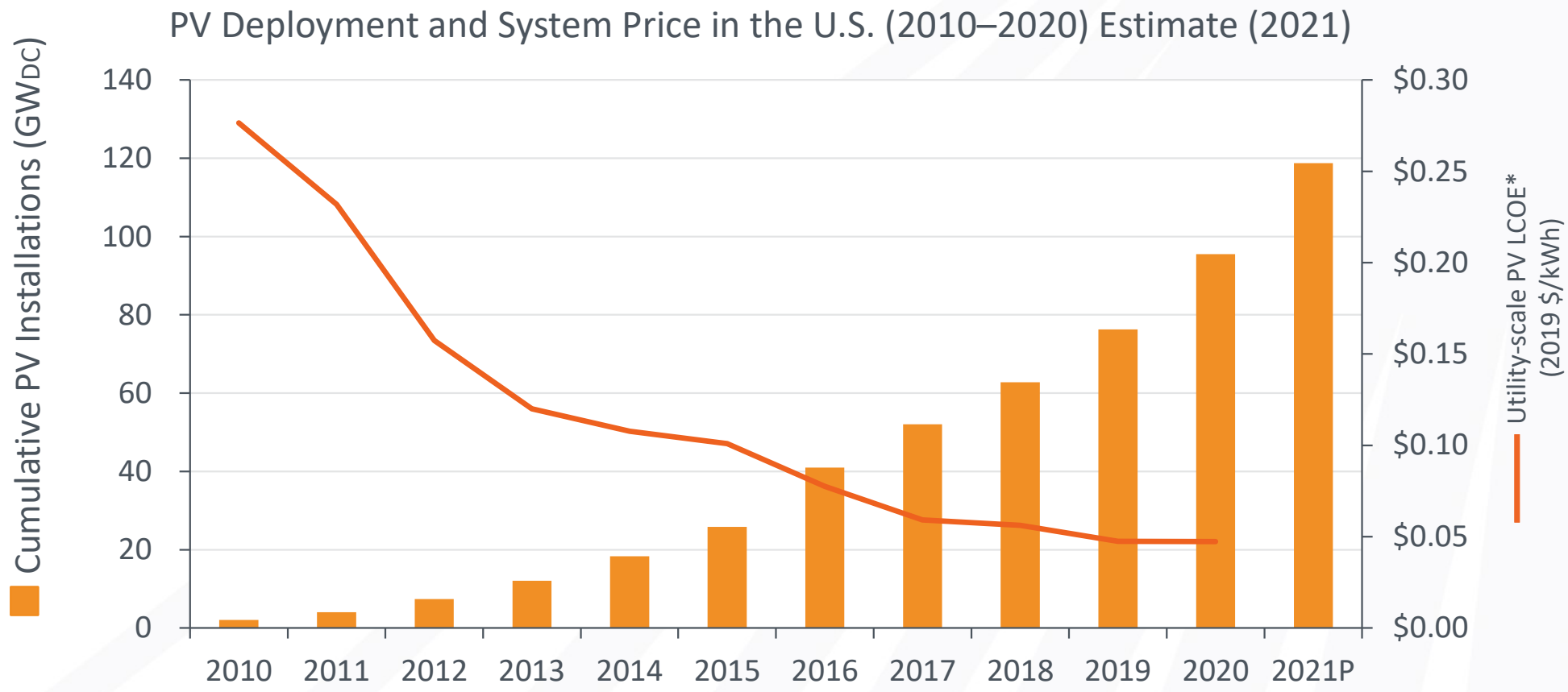
2020 Global energy sector CO_2 emissions from fuel combustion



Global emissions avoided by PV (2.8% of total emissions)

https://iea-pvps.org/trends_reports/trends-in-pv-applications-2021/

U.S. Solar: Falling Costs, Rising Deployment



*Price is depicted as levelized cost of energy (LCOE)

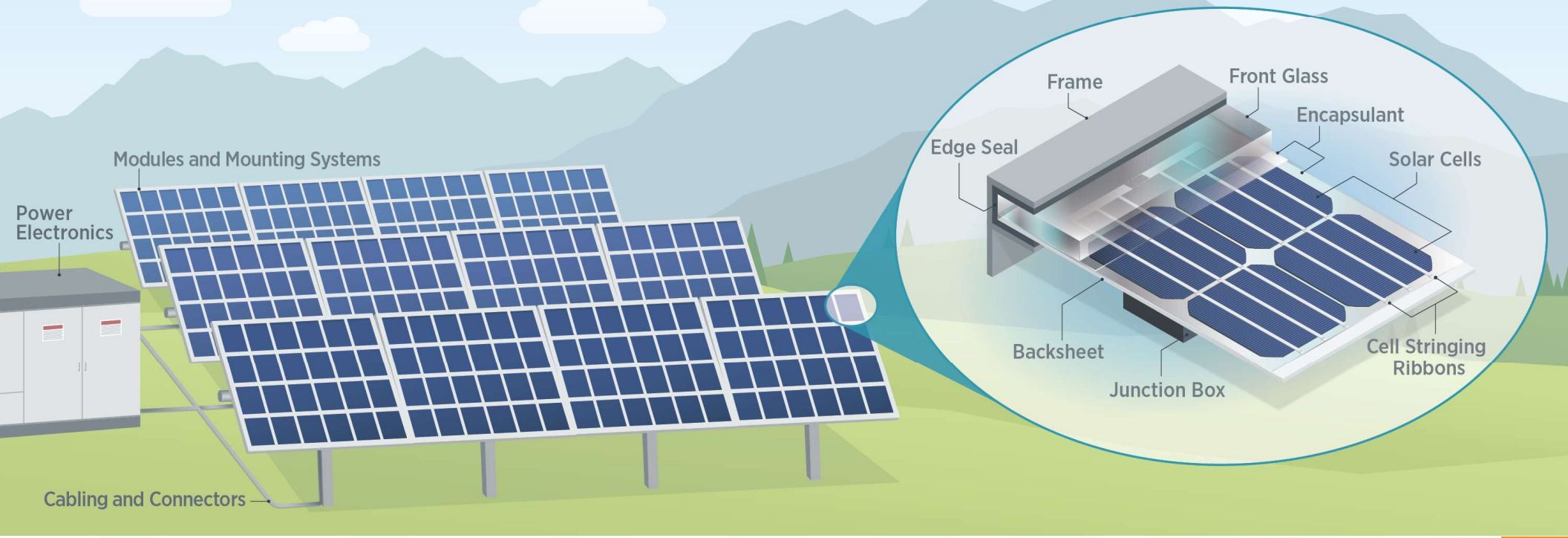
Sources: National Renewable Energy Laboratory, "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2019"; Wood Mackenzie Power & Renewables/SEIA U.S. Solar Market Insight.

2030 SETO Photovoltaic Goals

Photovoltaic (PV) electricity costs less than 2 cents/kWh

Seamless integration with other land uses

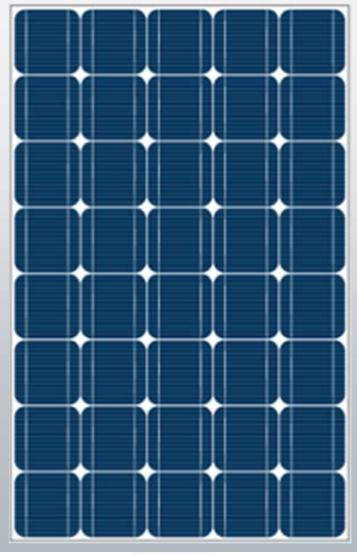
Reduced overall PV system life cycle impacts



Photovoltaic System Elements

PV Modules

37% of utility-scale system cost



Electrical & Structural BOS

21% of utility-scale system cost



Inverter

4.5% of utility-scale system cost



Source: National Renewable Energy Laboratory. U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks: Q1 2021" https://www.nrel.gov/docs/fy22osti/80694.pdf

A Pathway to $0.02/kWh for Utility-Scale PV

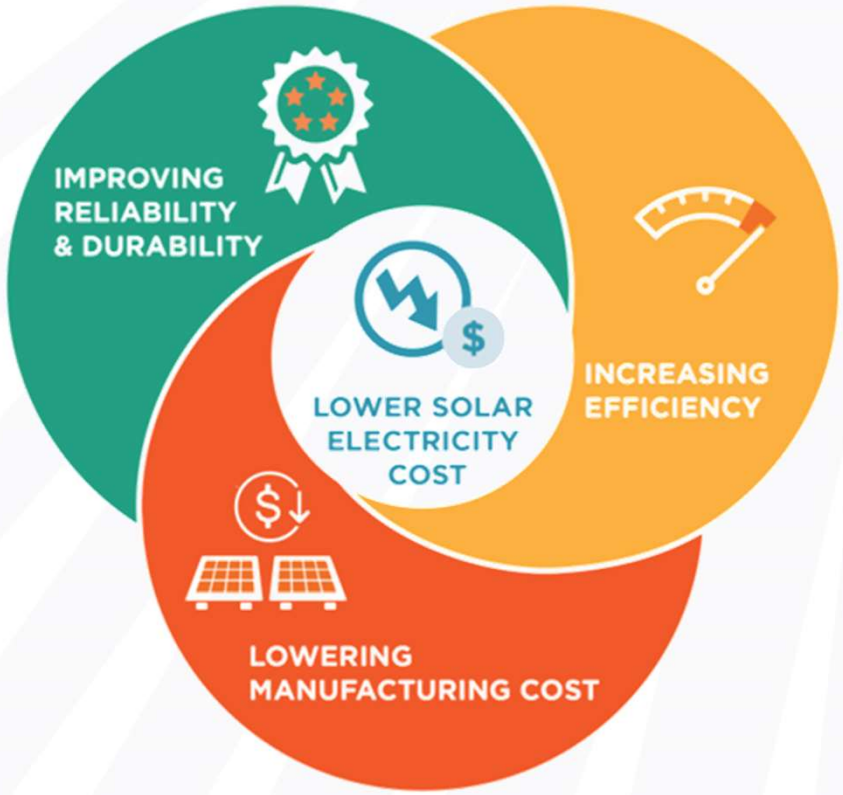


The Photovoltaics Subprogram Approach

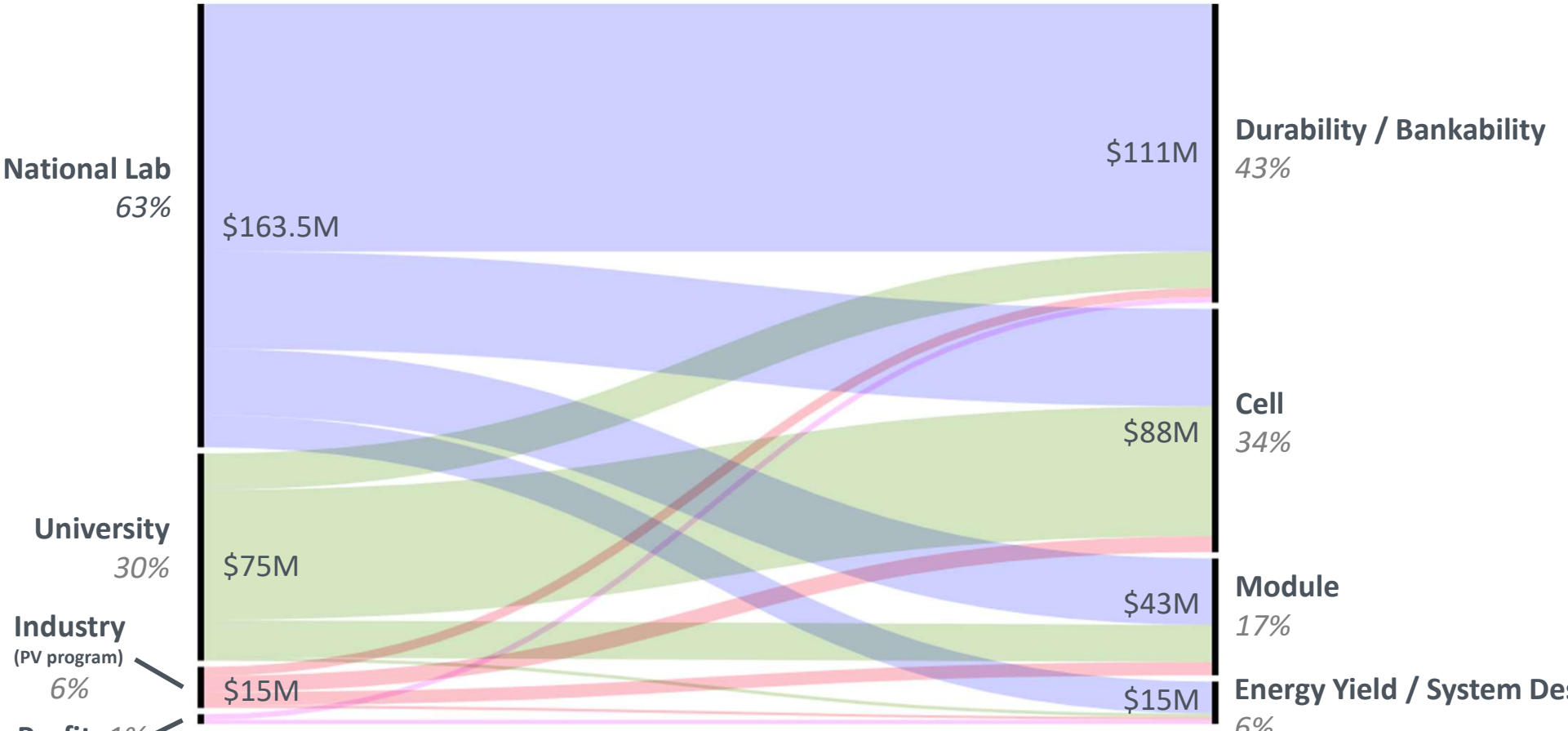
Funds research with a 3-15 year horizon, which is beyond industry focus or capabilities

Supports an innovation ecosystem that includes universities, students, professors, and the private sector

Fosters the transition of research developments into the marketplace

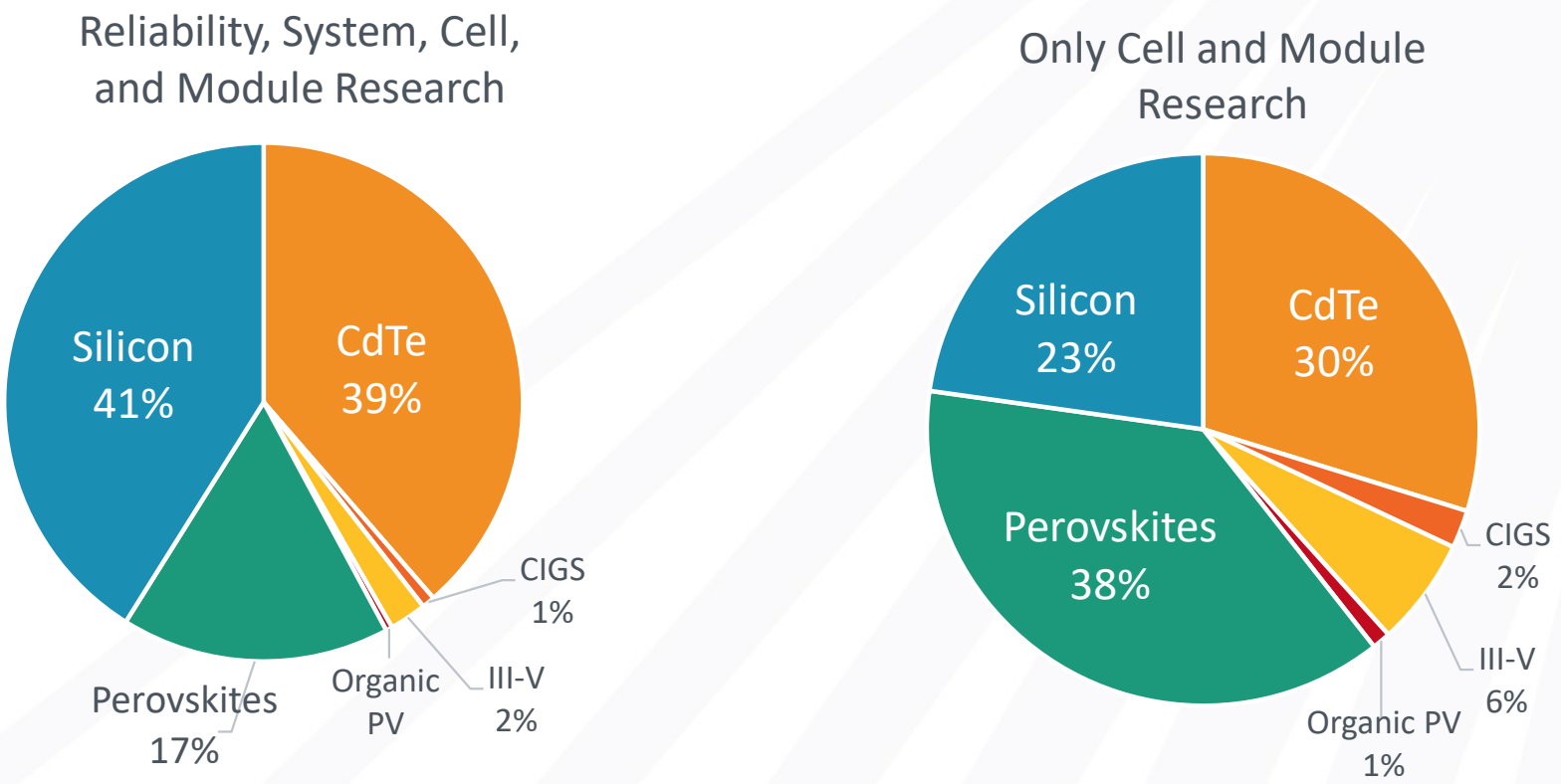


SETO PV Research Funding Allocation - 2022 ($257M)



SETO PV Research Funding Allocation - 2022 ($257M)

PV Absorber Tags by Funding



Includes projects under negotiation and recent starts not formally included in 2022 Peer Review; individual projects have multiple tags

Evolutions Of Existing Commercial Technology R&D

- $65M portfolio in FY2022 peer review
- Federal funds used to accelerate advancement in the most competitive technologies
- Bulk of funding directed to CdTe and Si PV

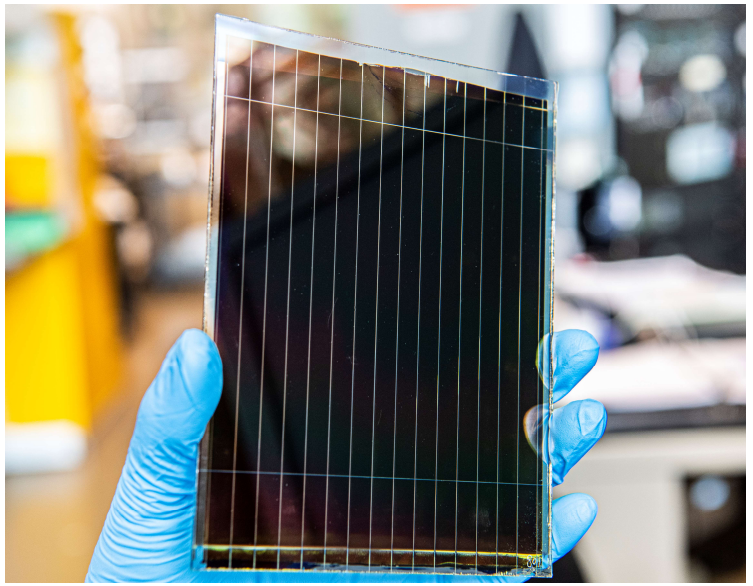


Examples:

- Passivation and heterojunction Si cells
- Understanding defects to increase CdTe performance
- Metallization and paste development
- Low-cost manufacturing processes for III-V PV technologies

Emerging Cell and Module Technology R&D

- $51M portfolio in FY2022 peer review
- Diversified R&D portfolio to enable potentially radially low-cost PV
- Focus on areas where the US could have a competitive advantage or strategic capability

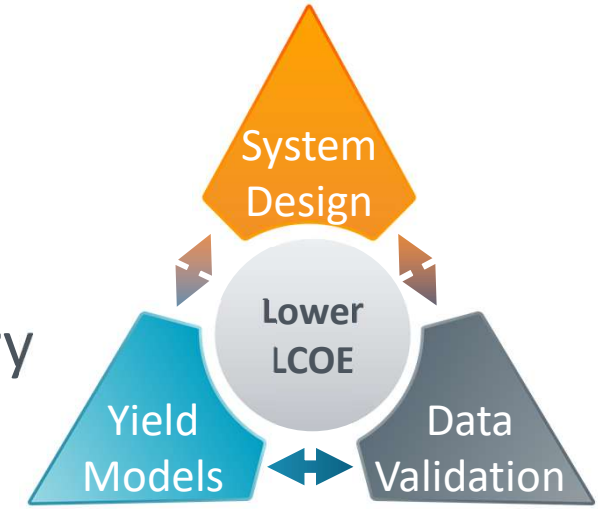


Examples:

- New Perovskite PV cell architectures to improve durability
- Tandem modules
- New materials development for advanced contacts

Research to Ensure PV Delivers as Expected

- $50M portfolio in FY2022 peer review
- System lifetime dramatically affects LCOE but systems must be reliable and financeable
- PV deployment is accelerating, and the industry needs to be able to predict, understand, and mitigate degradation



- SETO is increasing efforts on BOS system durability and best practices

Examples:

- Collecting, analyzing, and disseminating PV performance data
- Core National Laboratory work to support standard testing procedures

Advanced System Designs and Increasing Energy Yield

- $13.5M portfolio in FY2022 peer review
- R&D to increase the energy yield (kWh/kW) in a variety of climates
- Expanding PV deployment options so that the solar resource can be more fully utilized



Examples:

- Characterizing bifacial gain and creating an albedo database
- Improved performance in snowy climates
- Improved tracking designs

SETO Multi-year Program Plan Published 5/4/21

Continuing cost reductions for incumbent technologies

→ Silicon, CdTe







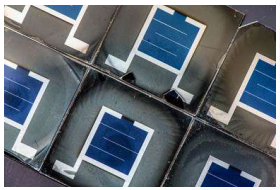
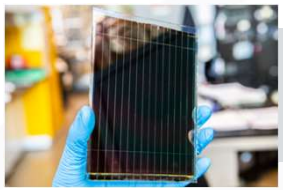
Improvements in system yield

→ Transition to bifacial, extended system operational life

Solutions that expand viable siting and improve installations

→ Varied terrain, canopy, floating



Improvement in module performance

→ Tandem modules, perovskites

Increased focus on sustainability

→ Supply chains, end-of-life considerations




www.energy.gov/eere/solar/articles/solar-energy-technologies-office-multi-year-program-plan

A quick recap

- PV research will help us achieve our goals of a carbon-free electricity sector by 2035 and 100% clean energy economy with net-zero emissions by 2050
- SETO PV research focuses on reducing cost, increasing durability, and increasing performance
- Expanding research portfolio in PV balance of systems durability, as well as in PV end of life and waste mitigation
- Looking ahead to technologies such as floating solar and agrivoltaics to further accelerate deployment

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SOLAR ENERGY TECHNOLOGIES OFFICE

2022 SETO PEER REVIEW

Keeping up with Industry

Encouraging Collaboration and Industry Involvement in Photovoltaics R&D Projects

Brion Bob, Technology Manager

Items to Cover

- Industry Involvement in Early-Stage Research
  - Perovskite Technology Transfer
  - CdTe PV Research Community
  - Silicon Cells, Modules, and Systems
- A Few Examples of Partnership-Focused Research Projects
  - 4 Partnership Focused Projects Focused on Cell, Module, and System Technologies
  - 2 Research Consortia in Important Research Areas



Industry Engagement in Early-Stage R&D

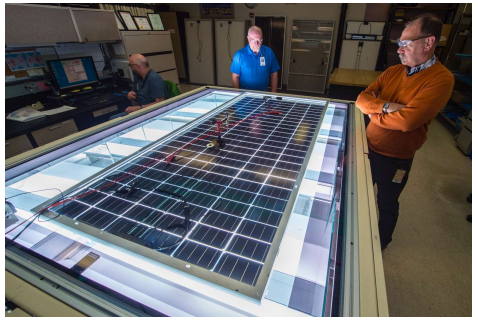
Previous Designs



State of the Art Technology



Future Technology



Industry Engagement in Early-Stage R&D

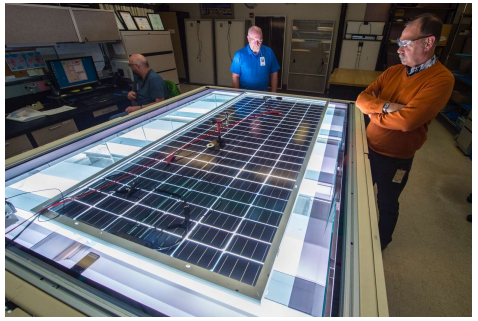
Previous Designs



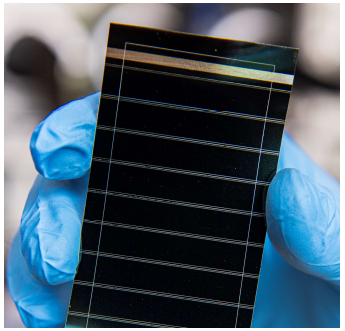


State of the Art Technology

Future Technology



Next Gen Innovations



State of the Art Deposition Systems and Materials

Perovskite Technology Development and Validation

Cell Design and Materials

State of the Art Deposition Technology

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

NREL Transforming ENERGY

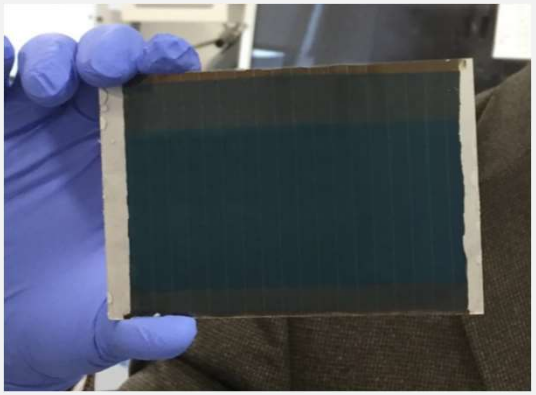
Arizona State University

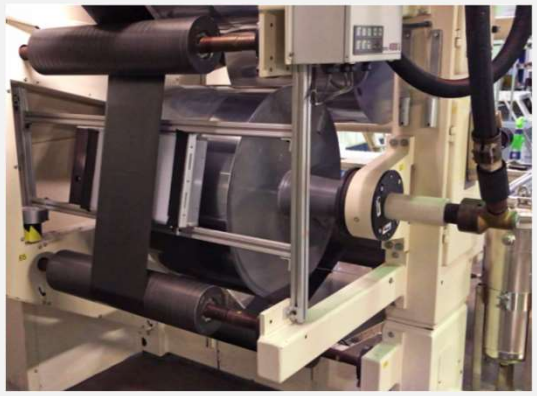
SLAC

EMC

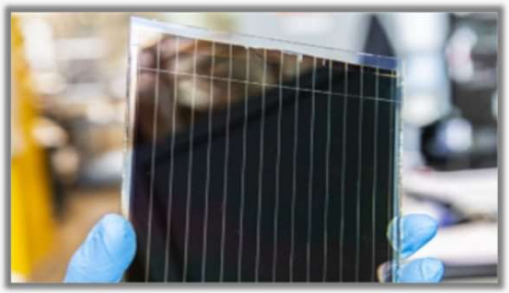
SWIFTCOAT

Other Collaborators:
Eastman Kodak
Corning





Project Goals: GW-scale Production at 90% Reduced CapEx from a Single Roll-to-Roll System

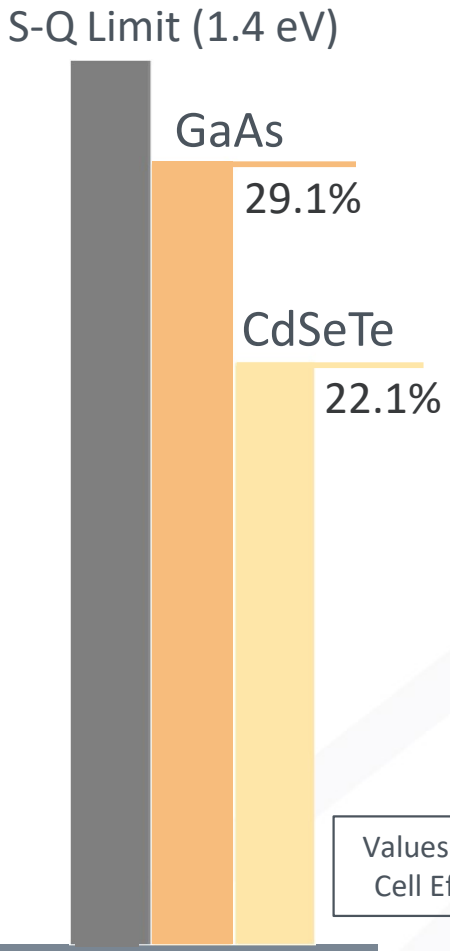


PV PACT

- Focused on Validating Perovskite Cell and Module Reliability
- Prototype Testing and Analysis Available

pvpact.sandia.gov

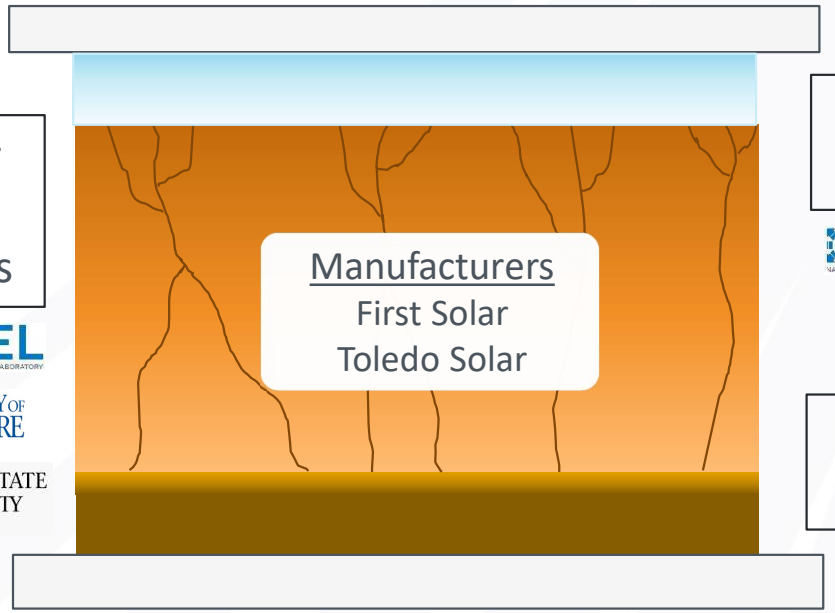
The Cadmium Telluride PV Community



Values from the NREL Cell Efficiency Chart

Absorber Layer Deposition and Post-Treatments





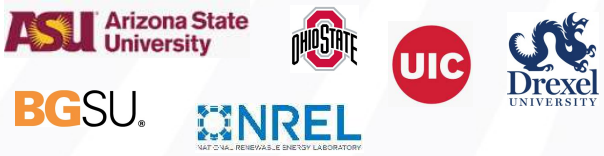
Front Contact and Junction



Rear Contact and Metallization



Loss Mechanism Analysis and Material Characterization



FY21 CdTe PV Accelerator Consortium

$13.5M solicitation released by NREL to support the initial 3 years of a consortium to enhance domestic technology leadership and the long-term competitiveness of CdTe PV

- Focus on cell performance, with expected goals of 24% efficiency by 2025 and 26% efficiency by 2030.
- The consortium will also work to advance and grow domestic CdTe PV production and maintain sustainable module prices that are competitive with imported PV modules.

The Consortium Will:

- Convene domestic research and guide new solicitations to address CdTe R&D goals.
- Maintain technology roadmaps outlining CdTe research priorities
- Assess opportunities to expand the US CdTe manufacturing base

Stay Tuned for Further Announcements

Selected Projects Focused on Partnering

Total Active Cycle Funding across all Four Programs: $52M



PV Foundry

- Provides Silicon Cell and Module Fabrication Support and Collaboration

Arizona State and Georgia Tech



PV Proving Grounds

- Operates the Regional Test Centers to Validate New Technologies

rtc.sandia.gov



PV Fleet Data Initiative

- Studies System Performance Data and System Power Loss at the Fleet Level

pvfleetdata@nrel.gov

DuraMAT
Durable Module Materials Consortium

The DuraMat Consortium

- Focused on improving PV module materials, design, and overall reliability
- Able to fund research projects to accomplish its goals

More Information: Duramat.org

Thank You!

The SETO newsletter highlights the key activities, events, funding opportunities, and publications that the solar office has funded.



SIGN UP NOW:
energy.gov/solar-newsletter

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SOLAR ENERGY TECHNOLOGIES OFFICE

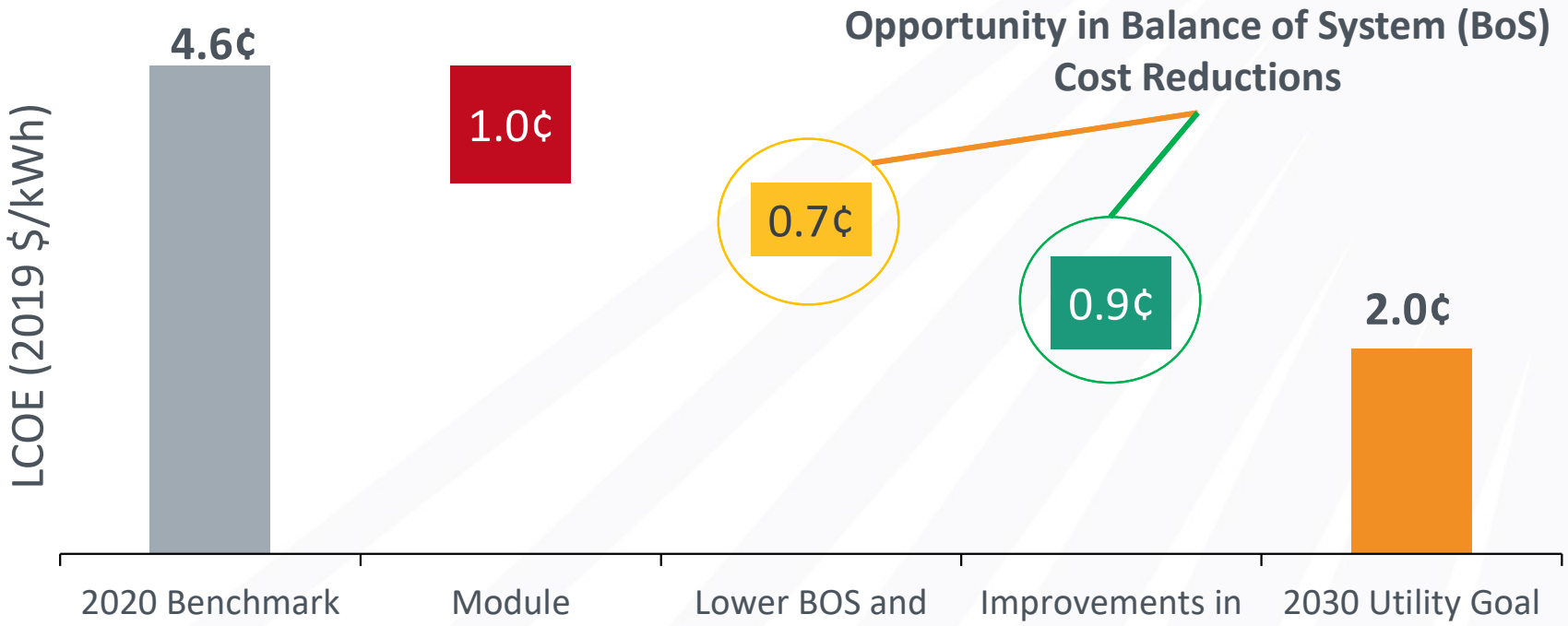
2022 SETO PEER REVIEW

PV Balance of System

Durability, Resilience and Cost Improvement

Allan Ward

A Pathway to $0.02 per kWh for Utility-Scale PV



PV Balance of System (BoS) Areas of Focus ($24M)

Durability

- Quality-Driven Failures
- 50-Year Service Life

Resilience

- Rapid Fault Detection
- Extreme Weather Recovery

Machine Learning

- O&M Optimization
- Multiscale Analysis

Inverter Reliability

- Root-Cause Analysis
- Predictive Analysis

PV BoS Focus Area: Durability

- Connectors and cabling installation quality and 50-year durability
- Fastener installation quality and 50-year durability for racking
- Latent damage effects from extreme weather (snow, wind)



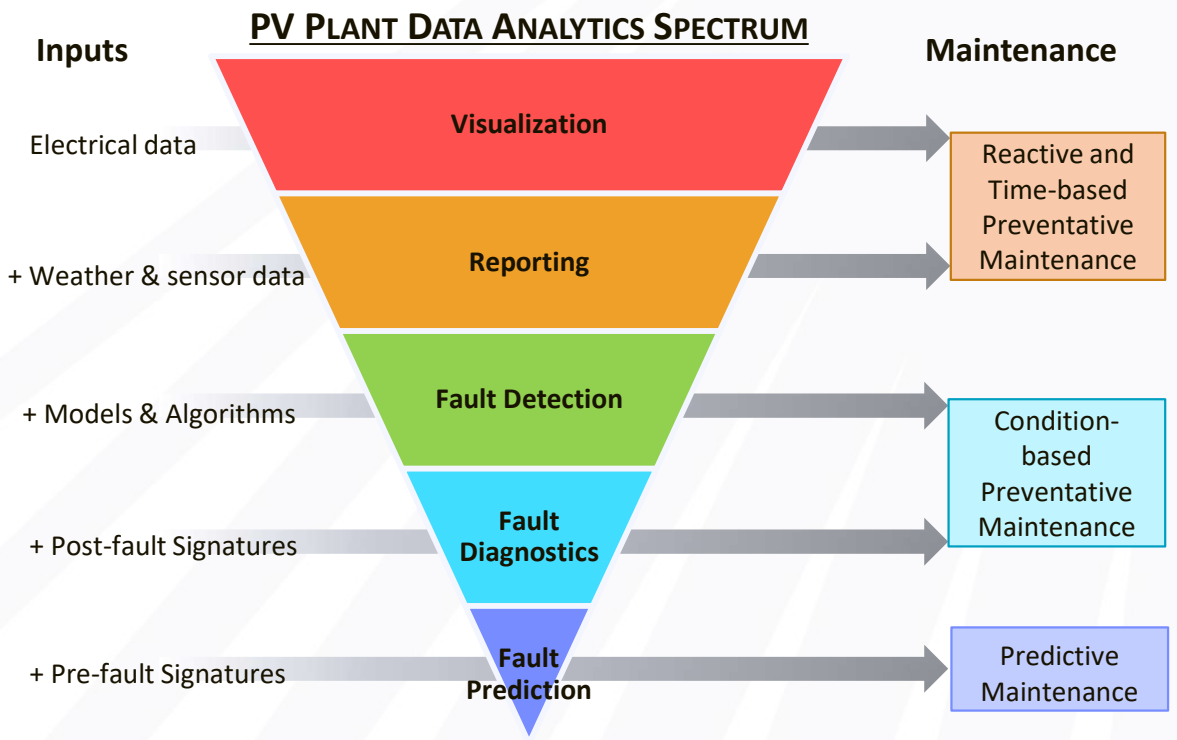
PV BoS Focus Area: Resilience

- Automated fault detection and localized under-performance identification
- Rapid O&M detection, response, and recovery after extreme weather events
- Modular power block development for inverters



PV BoS Focus Area: Machine Learning

- Automated detection and diagnostics to optimize O&M costs
- Multi-scale, multi-climate data analytics for future energy output prediction



Sources: *Data Analytics for PV Systems: Fault Detection and Diagnostics.* EPRI. Palo Alto, CA: 2019. 3002015051.

PV BoS Focus Area: Inverter Reliability

- Digital twin and Physics-of-Failure modeling for energy prediction and inverter design optimization
- Electrical impedance identification of emerging inverter faults



PV BoS Principal Awardees























Thank You!

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2022 SETO PEER REVIEW

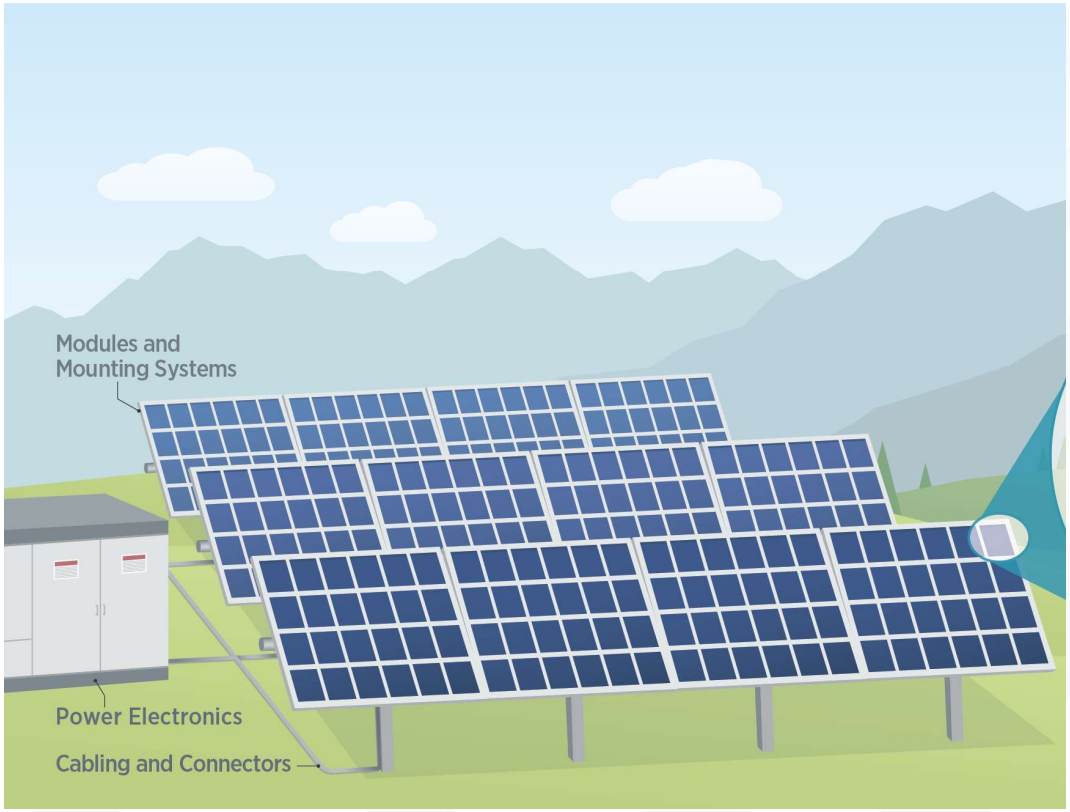
Photovoltaics End-of-Life

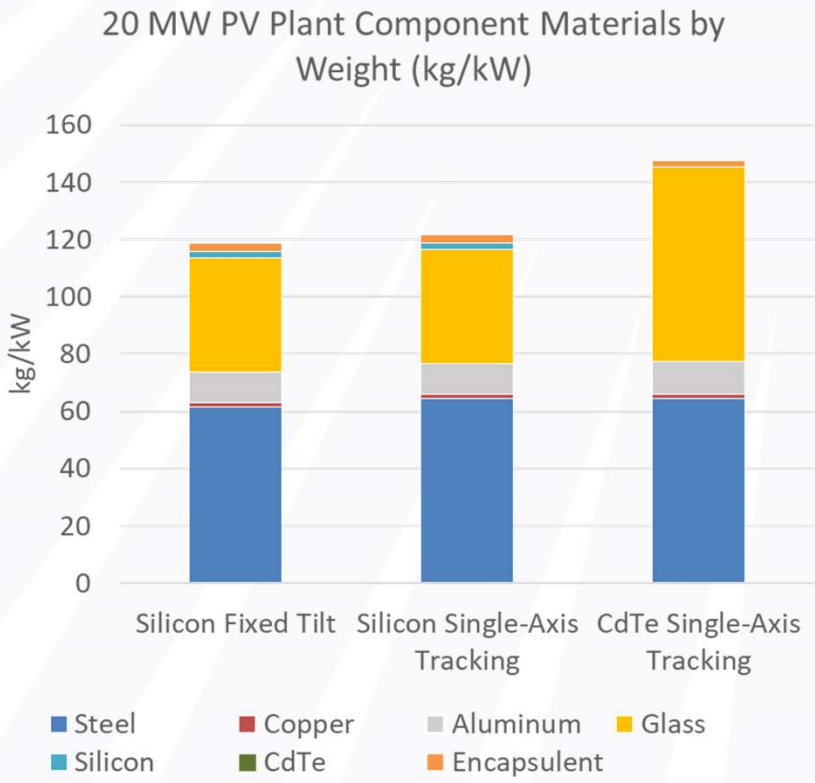
Susan Huang

Technology Manager

Materials in Plants

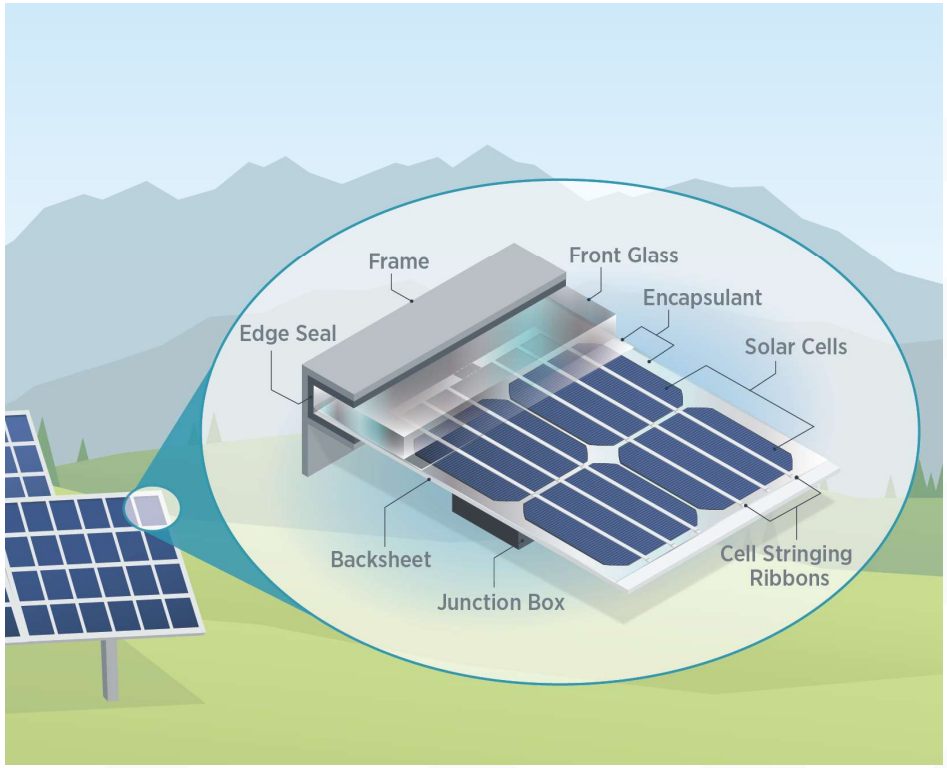
- At end-of-life (EOL), majority of plant material is recyclable

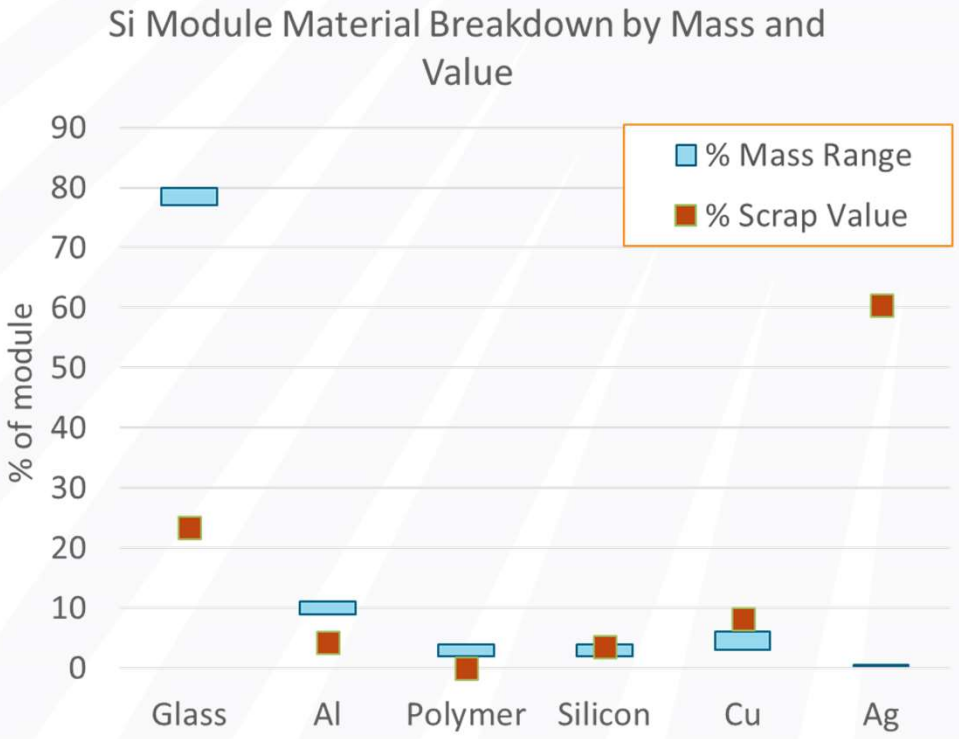




EOL PV Modules

- Recycling can be improved to recover materials and lower cost





Current PV Module Recycling Processes

- Cost to generator: Recycling is ~10X more than landfilling



EOL PV Modules

- Need to ensure safe disposal

TABLE 2: TCLP TEST RESULTS FOR ONE C-SI MODULE BY SAMPLING APPROACH: PROPORTIONAL, REPRESENTATIVE OR RANDOM (ND = NOT DETECTED)

Analyte	Result mg/l			Reported Detection Limit mg/l	Limit mg/l
	Proportional method	Representative method	Random method		
Arsenic	ND	ND	ND	0.1	5
Barium	ND	ND	ND	0.1	100
Cadmium	ND	ND	ND	0.1	1
Chromium	ND	ND	ND	0.1	5
Lead	2.96	2.48	4.01	0.1	5
Mercury	ND	ND	ND	0.01	0.2
Selenium	ND	ND	ND	0.1	1
Silver	ND	ND	ND	0.1	5



G. TamizhMani, et al., "Sampling Methods for Toxicity Testing of PV Modules for End-of-Life Decisions", 48th IEEE PVSC Proceedings, 2021.

PV EOL Policies

EPA United States Environmental Protection Agency

Toxicity Characteristic Leaching Procedure

Takeback Program
- WA: 2017

Universal Waste
- CA: October 2015
- HI: June 2021



Pending Policies
- NJ: Recycling Commission
- NC: Management and Decommissioning of Renewable Energy

SETO PV EOL Activities

2019 → 2020 → 2021

PV Recycling FOA Topic

DOE, EPA Collaboration

SIPS Project

PV EOL RFI & Workshop

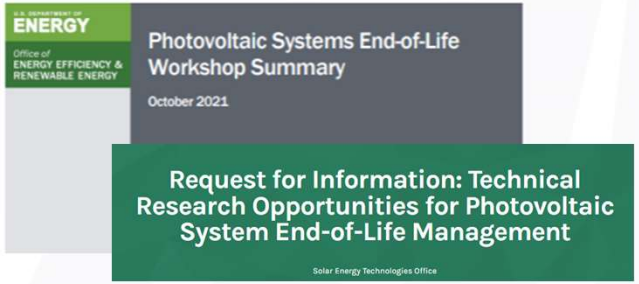
SIPS Project

IEA Task 12

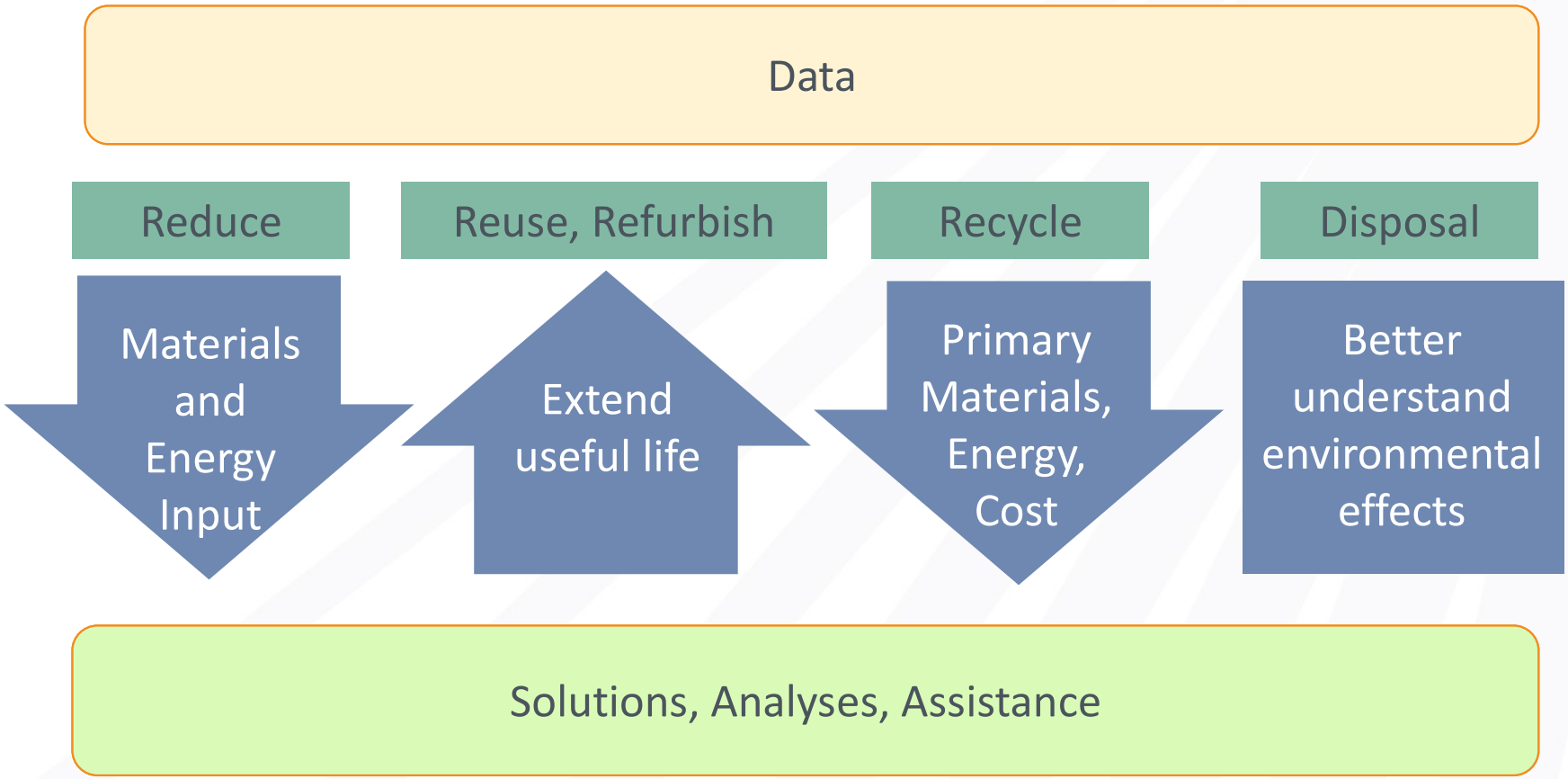
Solar Energy Technologies Office
FY2019
FUNDING OPPORTUNITY

EPA United States Environmental Protection Agency

Advanced Manufacturing Office



PV EOL Research Opportunities



PV EOL Future Work

- Infrastructure Investment and Jobs Act
  - $20M for PV Recycling and Safe Disposal
- EOL Database
- EOL Research Projects
  - Recycling cost target: 50% reduction
  - Industry engagement
- Continued collaborations with government and industry





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SOLAR ENERGY TECHNOLOGIES OFFICE

2022 SETO PEER REVIEW

Concentrating Solar-thermal Power

Avi Shultz

CSP Program Manager

Concentrating Solar-Thermal Power Team


Avi Shultz


Matt Bauer


Christine Bing


Patricia Clark

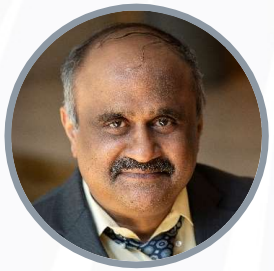

Tiffany Jones


Jonathan “Jo” Melville

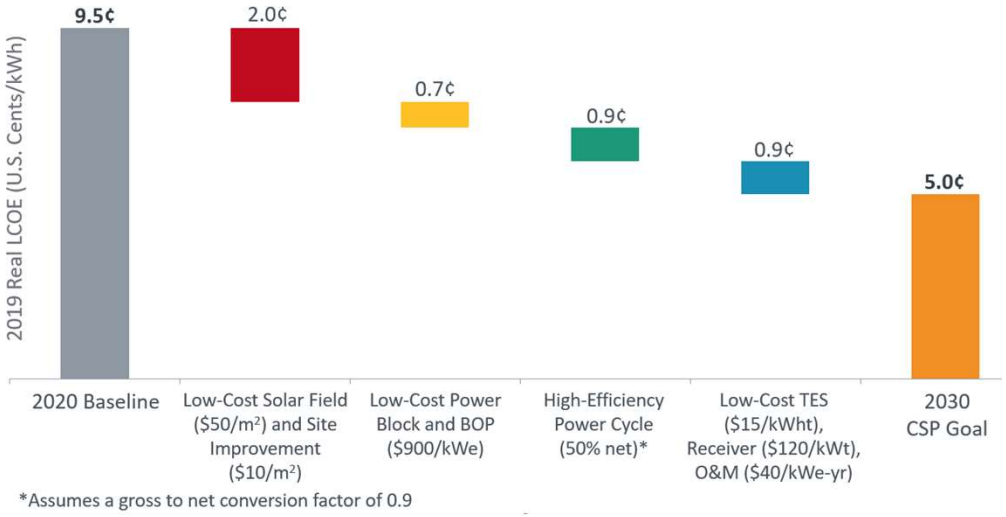

Shane Powers

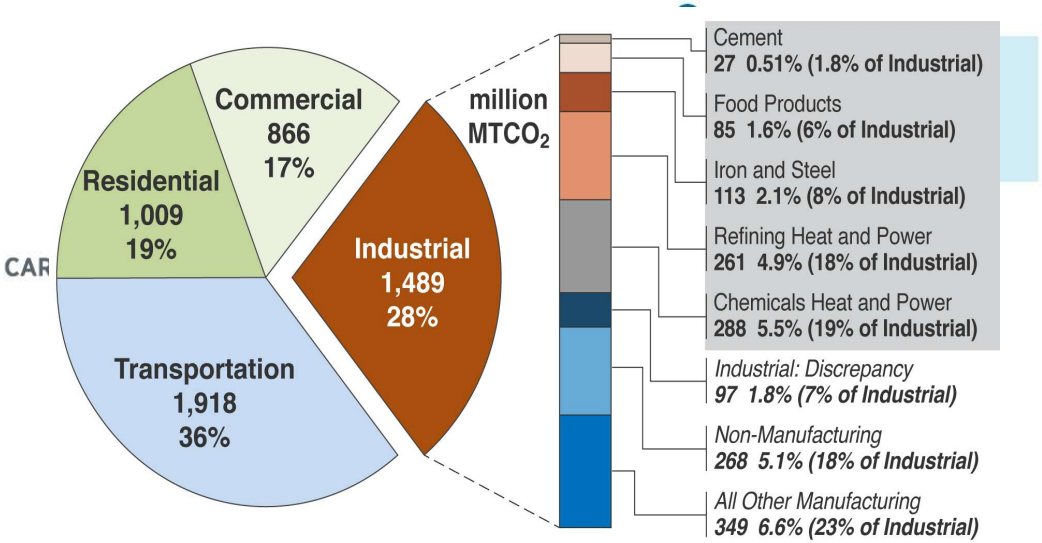

Andru Prescod


Kamala Raghavan


Rajgopal "Vijay" Vijaykumar

CSP Goals

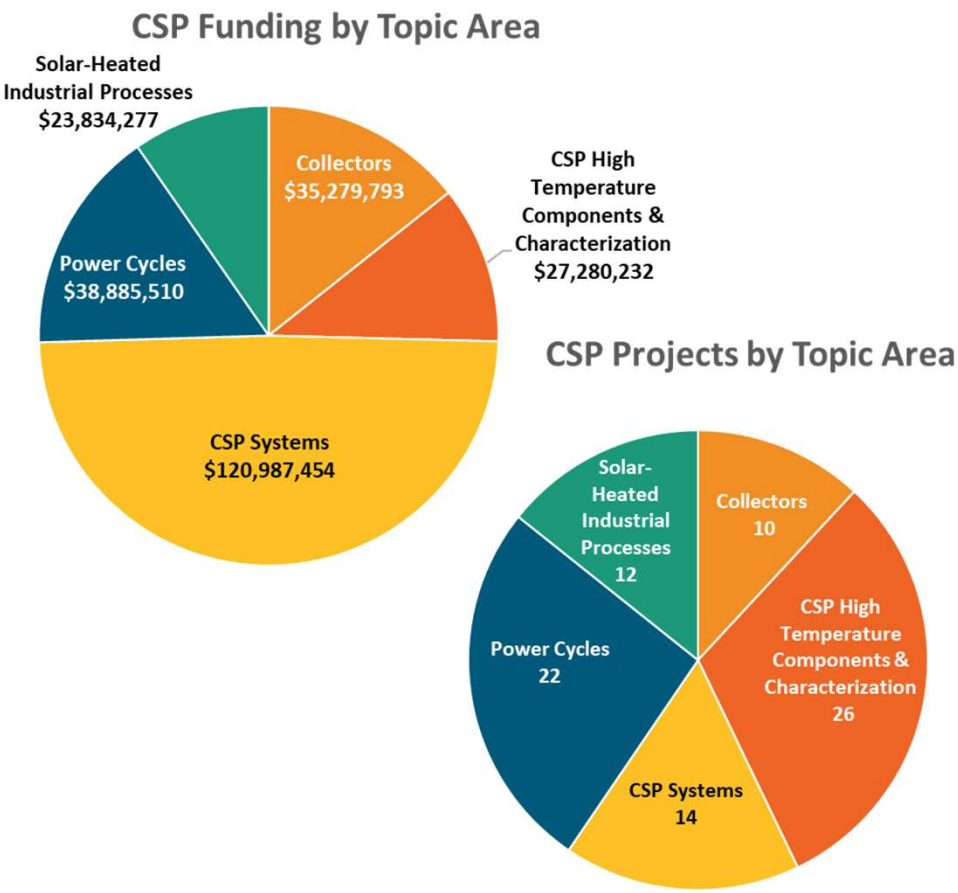




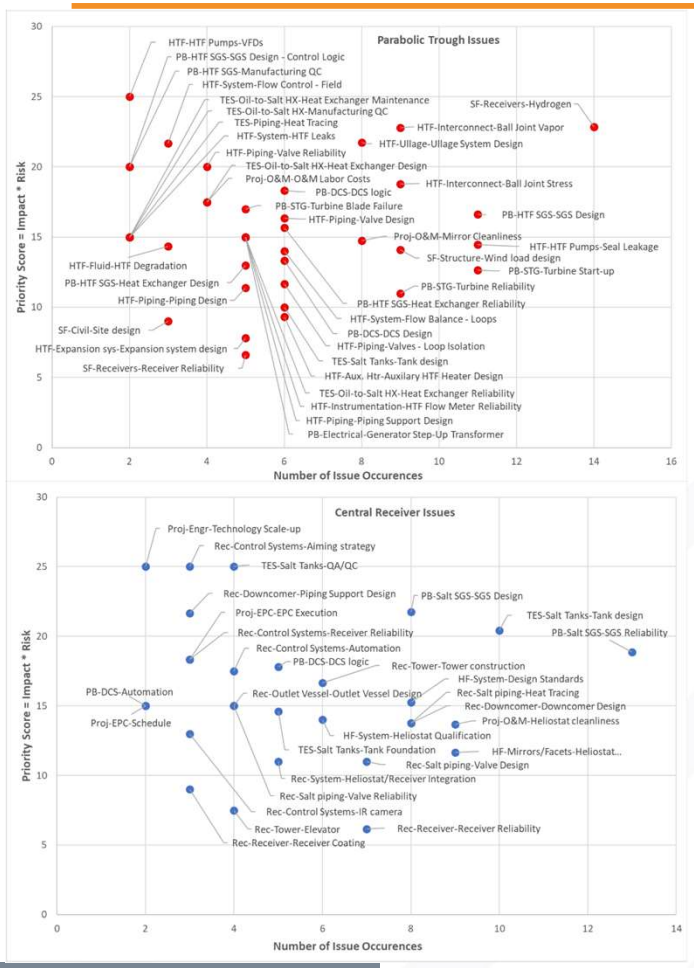
- Achieve LCOE goal through high efficiency power cycles operating at > 700 °C
- Reduce the levelized cost of heat, with thermal energy storage, to $0.02/kWhth, across a range of temperatures relevant to industrial processes

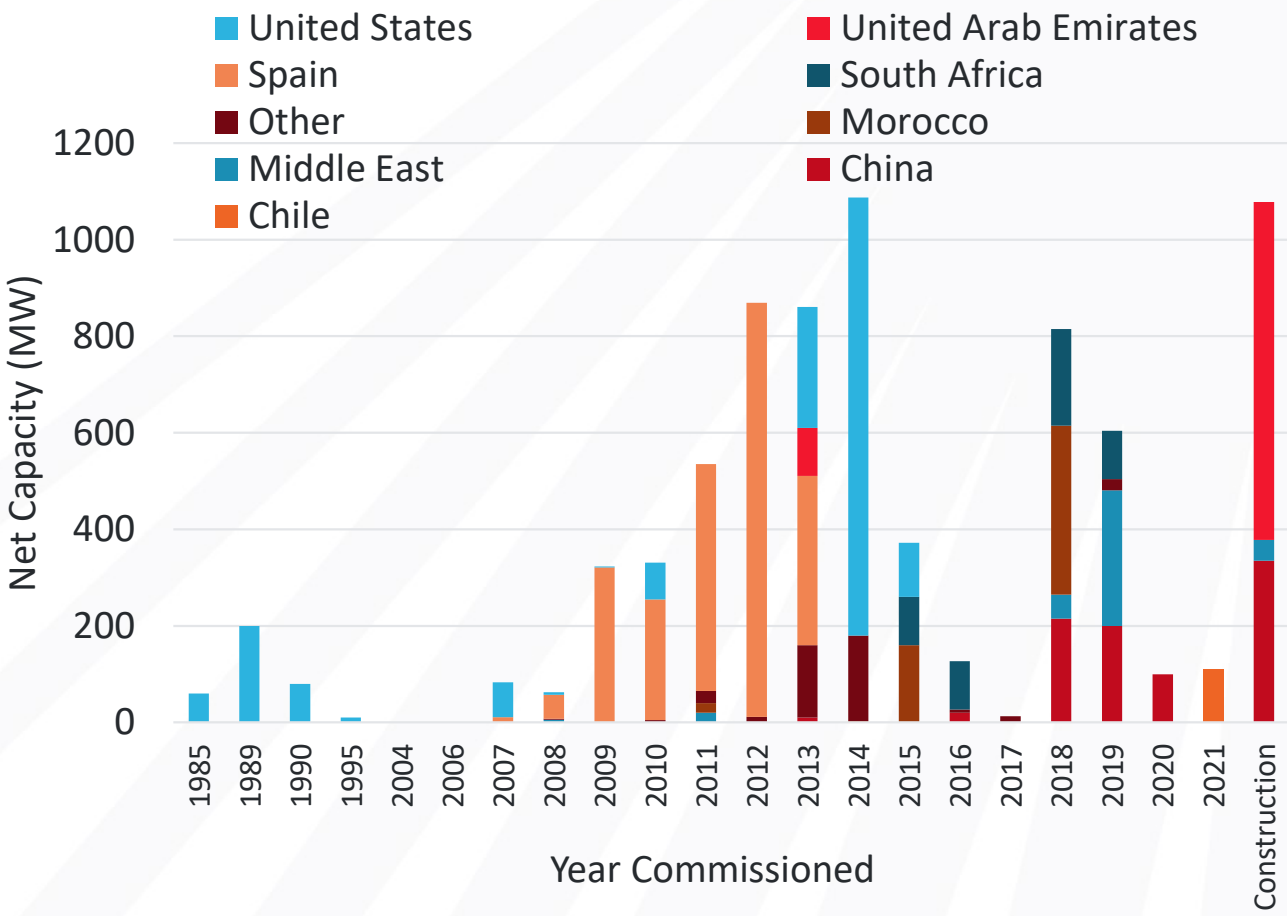
Active Funding Programs

FOA/Year	Funding	Topics
SETO FY 2021 PV/CSP FOA	**$30 million**	Solar R&R Pumped TES PERFORM/REFORM
FY 2022-24 National Lab Call	**$3 million** **$25 million** **$25 million**	Lab Core Capabilities Heliostat Consortium Lab R&D
Solar Desal Prize Round 2 (2021)	**$5 million**	
SETO FY 2020 FOA	**$39 million**	Integrated TESTBED
Solar Desal Prize Round 1 (2020)	**$10 million**	
SETO FY 2019 FOA	**$30 million**	Firm TES Materials and Manufacturing Autonomous Collector Fields
FY 2019-21 National Lab Call	**$3 million** **$23 million**	Lab Core Capabilities Lab R&D
Gen3 CSP FOA and Lab Call (2018)	**$85 million**	
Solar Desalination (2018)	**$21 million**	
SIPS (recurring)	**~ $3 million per round**	
SBIR (recurring)	***$XX million***	
Incubator (recurring)	***$XX million***	



Documenting CSP Best Practices





Mehos, et al., 2020, NREL/TP-5500-75763

Process Enhancement and Refinement for Operations, Reliability, and Maintenance (CSP PERFORM)

Topic	Project / PI	Lead Organization
Steam Generator Reliability	**Improved O&M Reliability for CSP Plants through Application of Steam Generator Damage Mechanisms Theory & Practice;** *PI: Michael Caravaggio*	EPRI
Nitrate salt tanks and components	**Improved Design Standard for High Temperature Molten Nitrate Salt Tank Design;** *PI: Javier Alvarez*	IDOM
	Failure Analysis for Molten Salt Thermal Energy Storage Tanks for In-Service CSP Plants; *PI: Julian Osorio*	NREL
	Design Basis Document/Owners Technical Specification for Nitrate Salt Systems in CSP Projects; *PI: Bruce Kelly*	Solar Dynamics
Sensors	**Evaluation of High-Temperature Sensors for Molten Solar Salt Applications;** *PI: Jon Lubbers*	Sporian
Plant design optimization	**CSP Plant Optimization Study for the California Power Market;** *PI: Hank Price*	Solar Dynamics
Operator performance	**Performance Improvement in CSP Plant Operations;** *PI: Michael Wagner*	U. Wisconsin

New projects (beginning in 2022) are addressing highest priority issues in CSP commercial reliability

Collectors – Past and Current Efforts

SUNVAPOR RENEWABLE PROCESS HEAT

Green Parabolic Trough Collector

Two design elements to achieve very low cost. 1) the use of a special grade of wood as the structural material, and the geometric arrangement of the structural members in a material-efficient typology.



Focused efforts have prioritized:

- Solar field capital cost reductions
  - Low-cost material replacements
  - Simplified heliostat and trough designs for faster assembly field deployment
- Improved metrology and characterization
  - Accelerate field calibration for improved energy output
  - Minimize operating costs through automated solar field analysis and controls

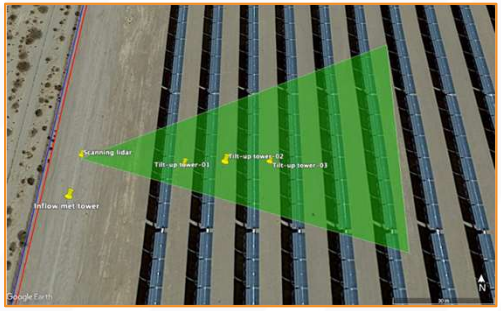
UFACET/NIO for Heliostats

UAV measurements of slope and canting errors in heliostats. Two approaches, using 1) a target heliostat and 2) the tower to determine errors.





NREL Transforming ENERGY | Sandia National Laboratories



Wind Loading on Heliostats

Goal is to better understand the physics drivers underlying the wind-loading experienced by CSP collector and support structures. Includes characterization of the prevailing wind conditions and resulting operational loads and the ability to predict wind-loading in deep-array installations.

NREL Transforming ENERGY

Collectors – Heliostat Consortium

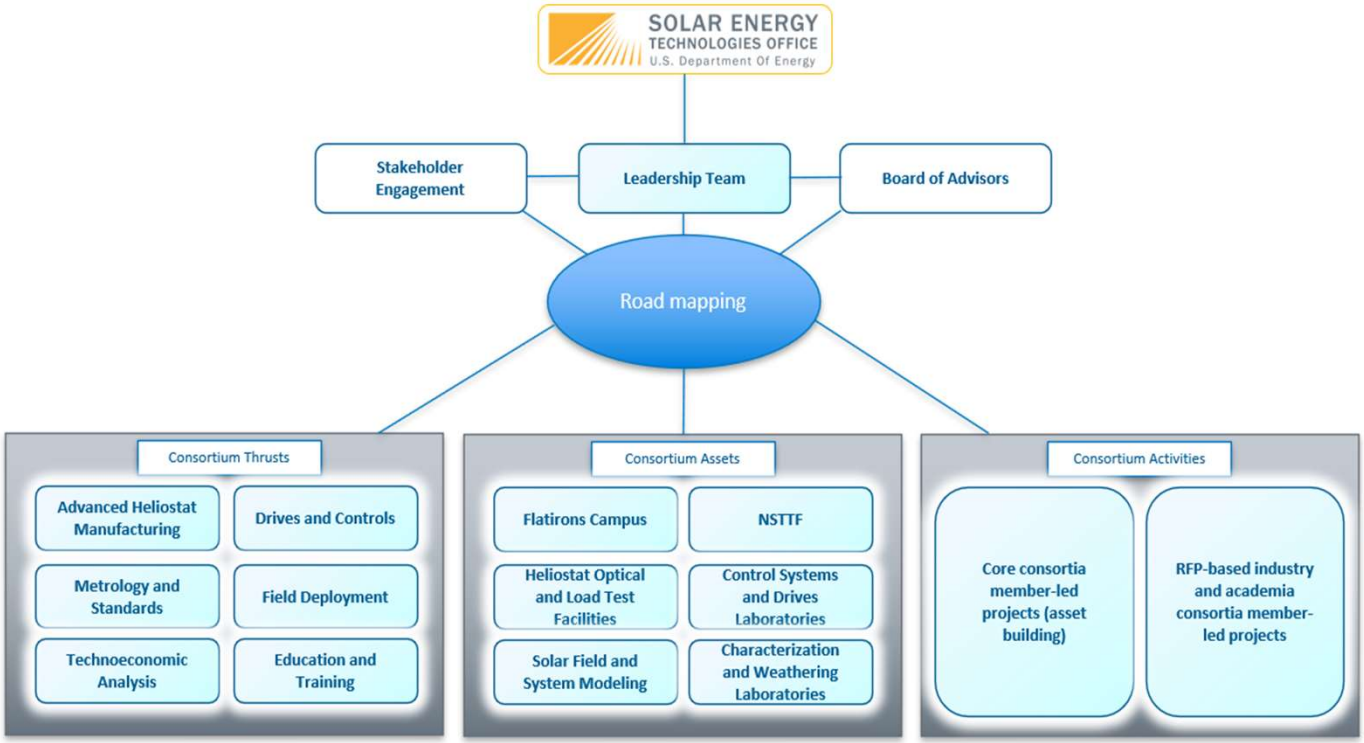
U.S. Department of Energy
HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

Consortium Goals

- Accelerate innovation in heliostat development and reliability
- Develop National Laboratory core capabilities and infrastructure.
- Encourage collaboration between the CSP industry and US researchers

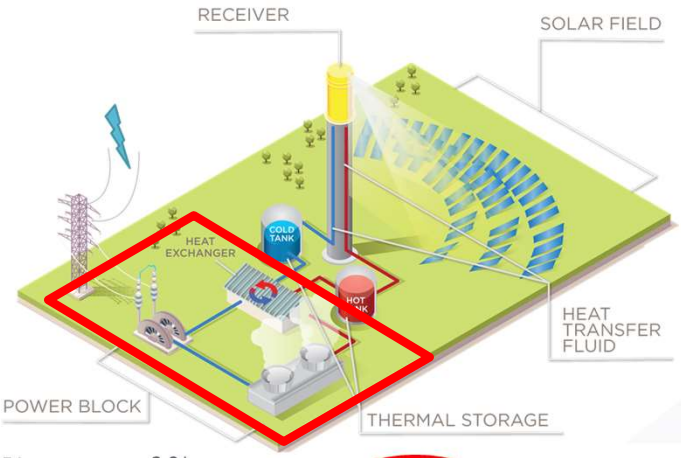
Consortium Structure

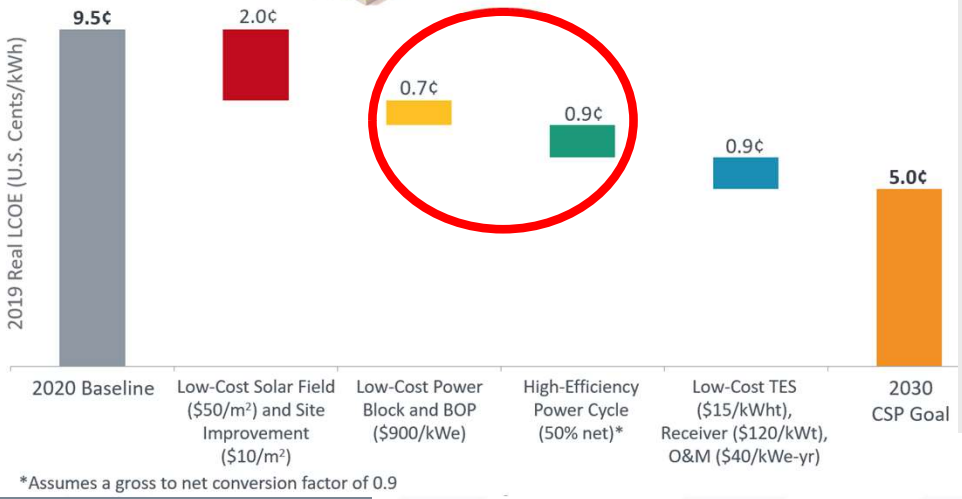
- 5-year, $25 million collaboration between NREL, Sandia, and ASTRI
- Periodic RFPs for collaboration between HelioCon and industry/academic researchers
- Emphasis on developing a diverse research and commercial workforce in CSP



NREL Transforming ENERGY
Sandia National Laboratories
ASTRI Australian Solar Thermal Research Institute
U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES OFFICE

Advanced Power Cycles





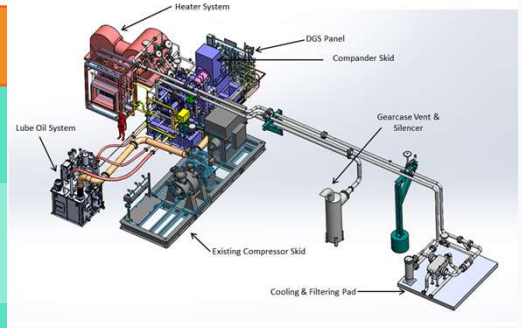
*Assumes a gross to net conversion factor of 0.9

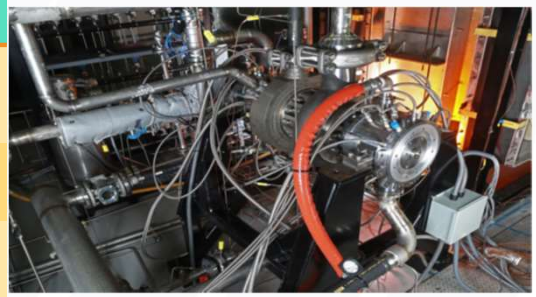
Programmatic Objectives

- Develop and demonstrate supercritical CO_2 power blocks consistent with > 50% net thermal-to-electric efficiency, including:
  - **Turbomachinery**
  - **Recuperators**
  - **Air cooling capability**
  - **Primary heat exchangers integrated with TES**
- Validate turbomachinery at MW_e scale ✓
- Support R&D on materials and manufacturing to **reduce cost to < $900 kW_e** for systems with **turbine inlet temperature > 700 ° C**
- Demonstrate commercially-relevant systems – with existing materials – at turbine inlet temperature approx. 600°C

sCO_2 Power Cycles – Completed and Ongoing Research

Component	Organization(s)	Status
Expander	Southwest Research Institute, GE Research	Successfully tested at 1 MW_e, 715°C for several hours
Compressor / Expander	Southwest Research Institute, Hanwha Power Systems	Successfully tested compressor and expander, at 1 MW_e to 715 °C; compressor inlet temperature to 36-37°C
Compressor	GE Research, Southwest Research Institute	Successfully tested compressor to inlet temperature 35°C
Seals	Southwest Research Institute, Eagle Burgmann	550-700°C dry gas seals being developed and tested
Bearings	GE Research	Gas bearing testing at large size
Air Cooler	Southwest Research Institute, Vacuum Process Engineering	Testing of MW_{th} sized air cooler



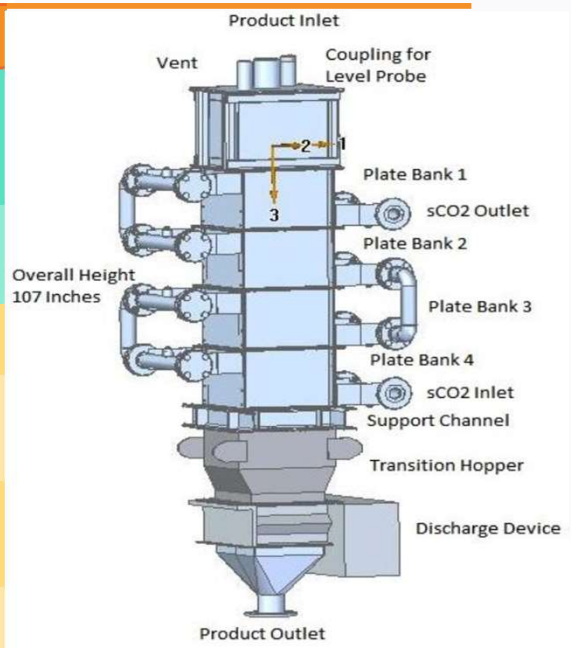


Remaining R&D challenges for power cycles > 700 °C :

- Low-cost manufacturing and fabrication for casing, recuperators, valves, air coolers
- Improved performance of seals and bearings to meet efficiency targets

Primary Heat Exchanger – Completed and Ongoing Research

Description	Organizations	Status
100 kW_{th} Moving Bed	Sandia, Solex, VPE	Tested at 550-715°C for several hours; design improvements identified to overcome low heat transfer coefficients measured
20 kW_{th} Moving Bed	Sandia, Solex, VPE	Successfully tested stainless steel heat exchanger at 500°C to 200 W/m^2-K
≤50 kW_{th} Moving bed	Sandia, Solex, VPE	High alloy heat exchange procured for testing
100 kW_{th} Fluidized bed	Sandia, Babcock & Wilcox, TU-Wien	Build and test heat exchanger at SNL 100 kW_{th} facility
≤20 kW_{th} Moving Bed	Sandia, Argonne, Ex-one	SiC heat exchanger being built for 500-700°C application
14 MW_{th} Moving bed	Solex	Scaleup of large size stainless steel heat exchanger



Remaining R&D challenges for primary heat exchangers > 700 °C :

- Nickel alloy PHE cost exceeds 300 $/kWth; 200-400 W/m2.K heat transfer coeff. unproven
- No functional molten salt-sCO2 heat exchanger design for testing

Integrated TESTBED (*T*hermal *E*nergy *St*orage and *B*rayton Cycle *E*quipment *D*emonstration)



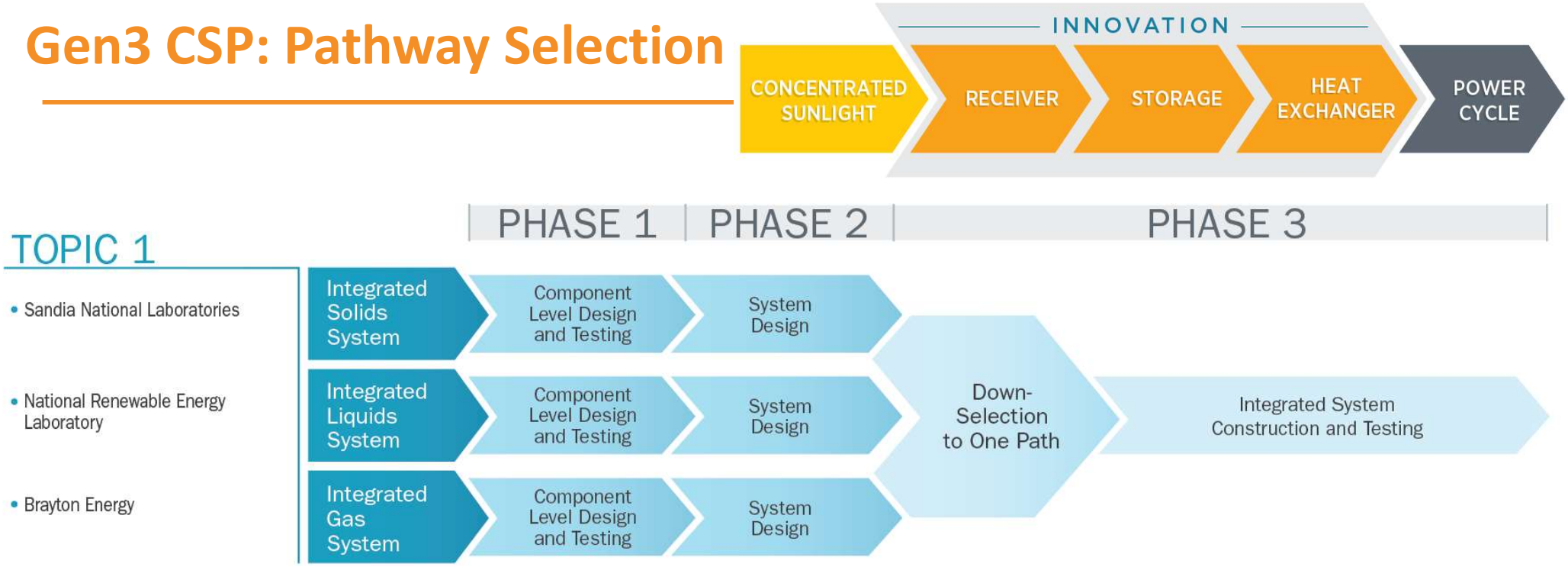
TESTBED

- First-of-a-Kind sCO_2 facility integrated with TES; heat input from solar field
- 5 MW_e sCO_2 cycle at 600°C turbine inlet
- Heat input from 36,000 heliostats, 26.3 MW_{th}
- 3 receivers 13.4 MW_{th} each, supply heat for 8 hour, 213 MWh_{th} solid particle TES

TESTING CAPABILITY

- Recompression Brayton Cycle (RCBC) operation
- RCBC control and integration with TES
- Turbomachinery durability and operation
- FOAK TES and heat exchanger

Gen3 CSP: Pathway Selection



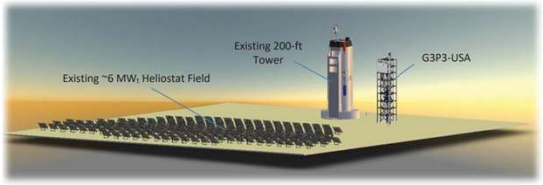
In March 2021, SETO announced that Sandia would receive $25 million to construct a MW-scale test facility at the National Solar Thermal Test Facility in Albuquerque, NM

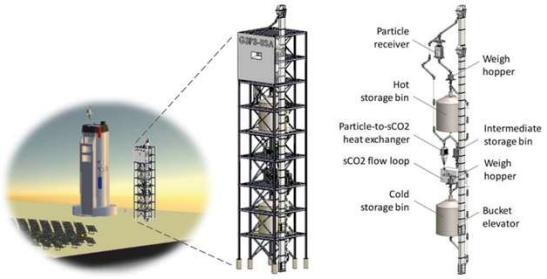
Gen3 CSP: Pathway Selection

TOPIC 1

- Sandia National Laboratories

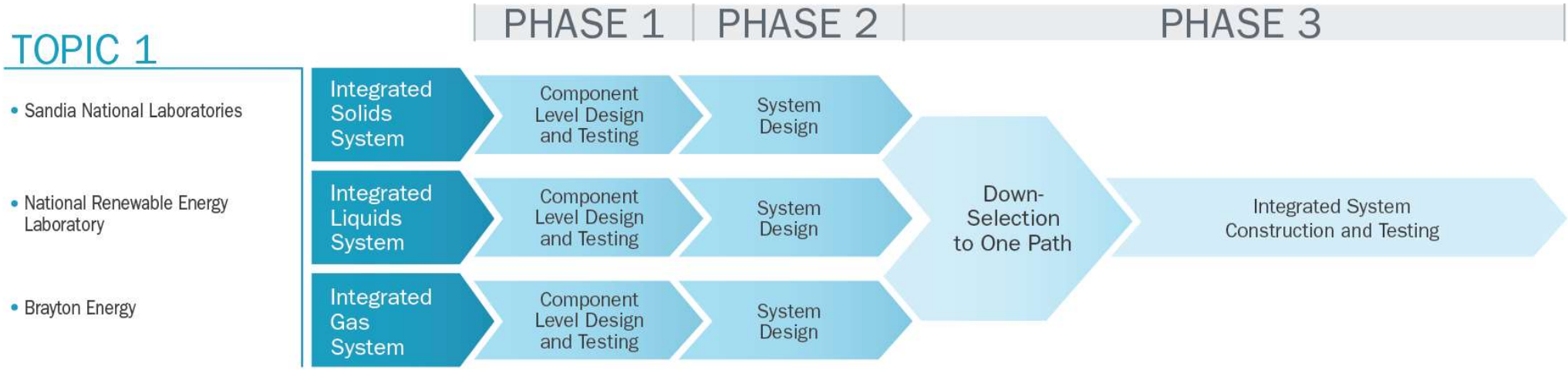
	PHASE 1	PHASE 2	PHASE 3
Integrated Solids System	Component Level Design and Testing	System Design	Down-Selection to One Path → Integrated System Construction and Testing
Integrated Liquids System	Component Level Design and Testing	System Design	
Integrated Gas System	Component Level Design and Testing	System Design	





- **Strengths:**
  - System simplicity for construction, operation, and reliability
  - Wide operating range and opportunity for further temperature increases
  - Potential relevance to other solar thermal applications
- **Remaining Gaps:**
  - Receiver optimization (also for controlled environments)
  - Particle cost
  - Demonstrations of flow control and particle handling at scale
  - Increasing system ΔT

Gen3 CSP: Future Needs for Liquid and Gas Pathways



• Liquid Pathway

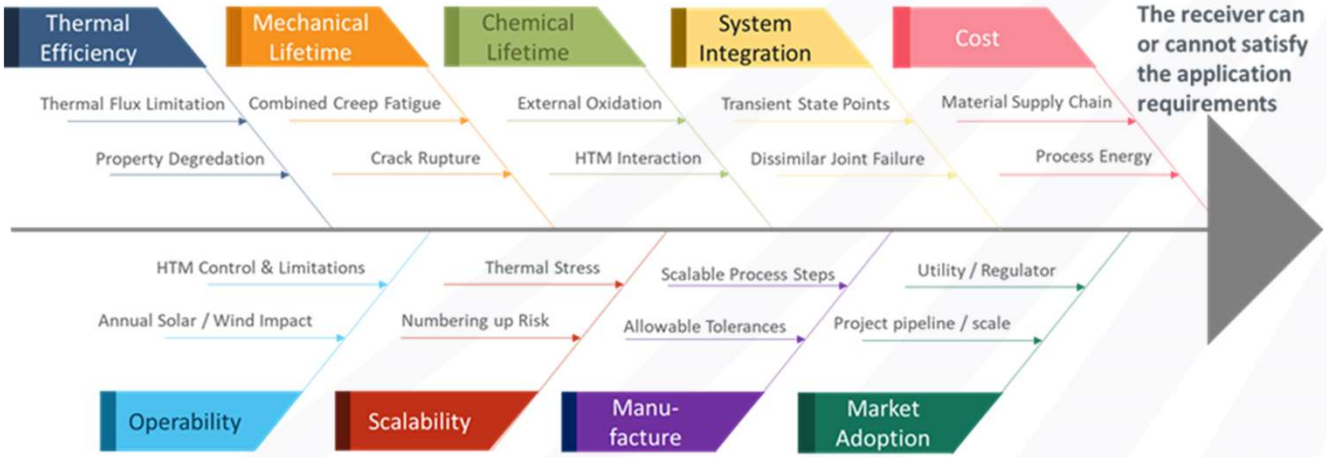
- Chloride salt is a promising low-cost TES media for multiple applications
- Validation of TES tank designs and chloride corrosion detection and controls
- Sodium receivers integrated with nitrate salt TES may lead to future adoption of chlorides

• Gas Pathway

- More testing needed to validate reliability of receivers for high-flux applications
- Particle TES design, and particle-to-gas HXer could benefit a wide variety of future applications
- System designs needed to minimize pressure drop

CSP High Temperature Components: Receivers and Reactors

Programmatic Goal: Support solar receiver and reactor de-risking frameworks to enable new heat transfer media, higher temperature systems, and solar thermochemistry



Active Research

- Particle Based Receivers
- Solar Fuels
- Ammonia Synthesis
- 750°C power cycles
- High temperature materials
- Lifetime modeling tools
- MW_{th} testing campaigns

Thermal Energy Storage Enabled Systems

- Concentrated Solar Energy
- Intermittent Renewables
- Nuclear Thermal Energy
- High Quality Unusable Heat
- Solar Chemistry

Thermal Energy Storage

- Dispatchable Power
- Seasonal Power Load Shifting
- High Quality Process Heat
- Clean Water & Low Quality IPH
- Thermal Chemistry

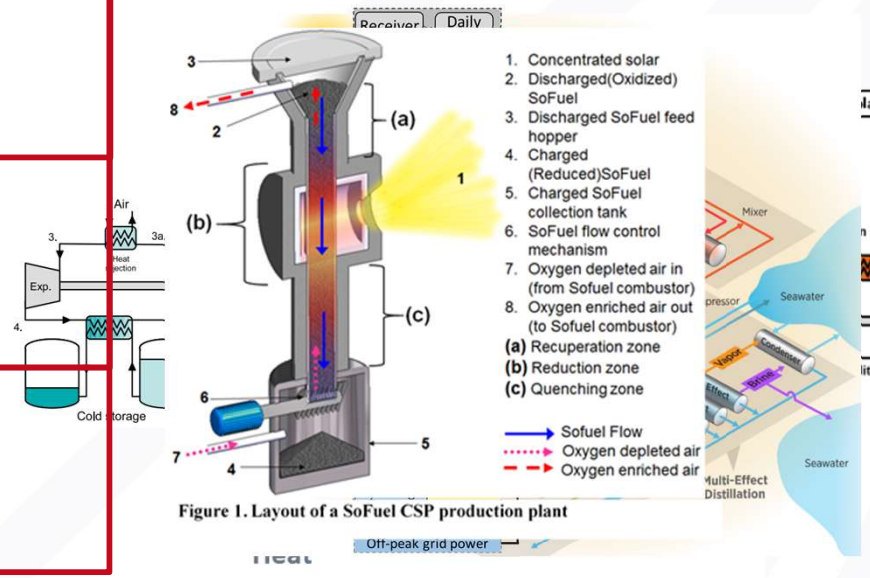


Figure 1. Layout of a SoFuel CSP production plant

Ellen Stechel, "Economic [illegible] Energy Storage for Advanced [illegible] Projects [illegible]"

James Klausner, "Solid State Solar [illegible] Duration Storage"

[illegible] et al. "Overview and design [illegible] Brayton cycle." *Desalination* 459 (2019): 20-33.

[illegible] (G3P3)." *AIP Conference Proceedings*. Vol. 2303. No. 1. AIP Publishing LLC, 2020.

High Temperature Characterization, Validation, Monitoring

Intrinsic Properties in Lab Environment

- Thermal transport, material flow, castability
- Fatigue Limit, Yield Strength

Accelerated Lifetime

- Performance pro
- Chemical and me

In Operation Local Pr

- Protype perform
- Technology scale

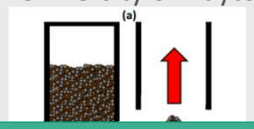
Commercial perform

- Control System Feedback and Operation
- Maintenance Planning

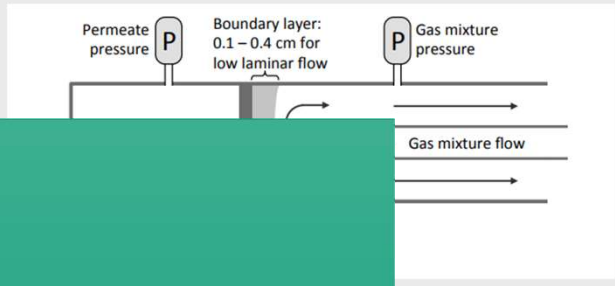
Challenges:

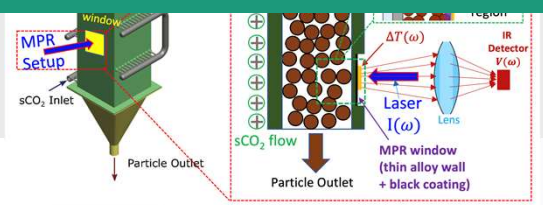
1. Harsh Environments
2. Nuanced Information
3. Data Reproducibility (FAIR Doctrine)
4. Environment Reproducibility
5. Long Term (Endurance) Testing

Andrew Schrader
University of Dayton

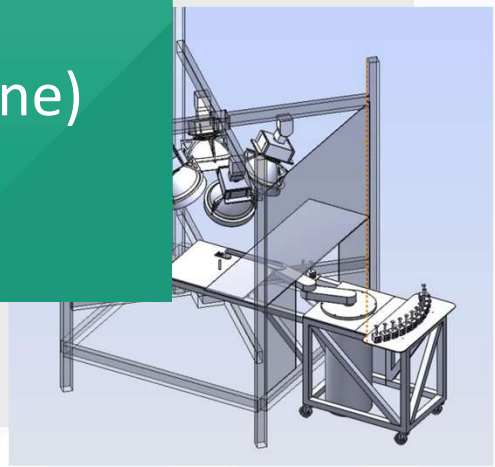


Greg Glatzmaier NREL





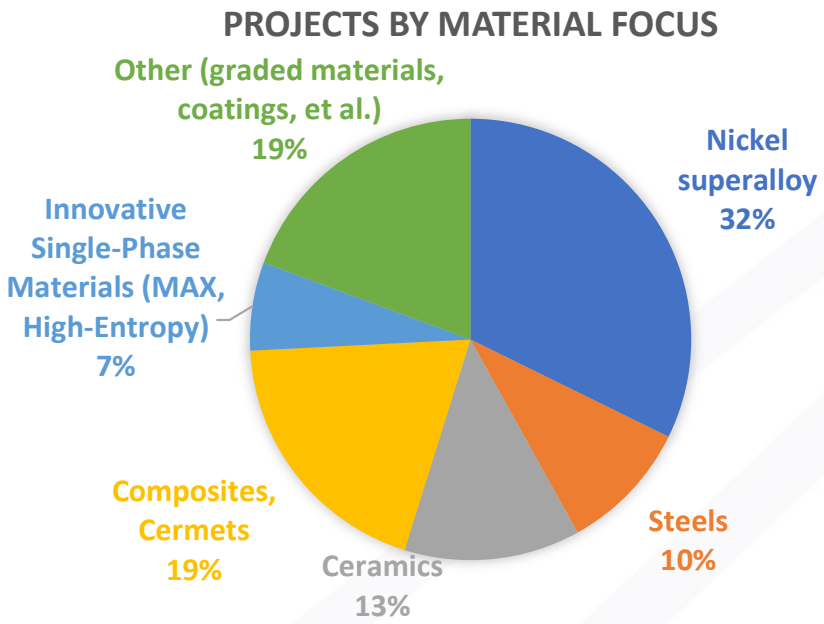
Renkun Chen UCSD

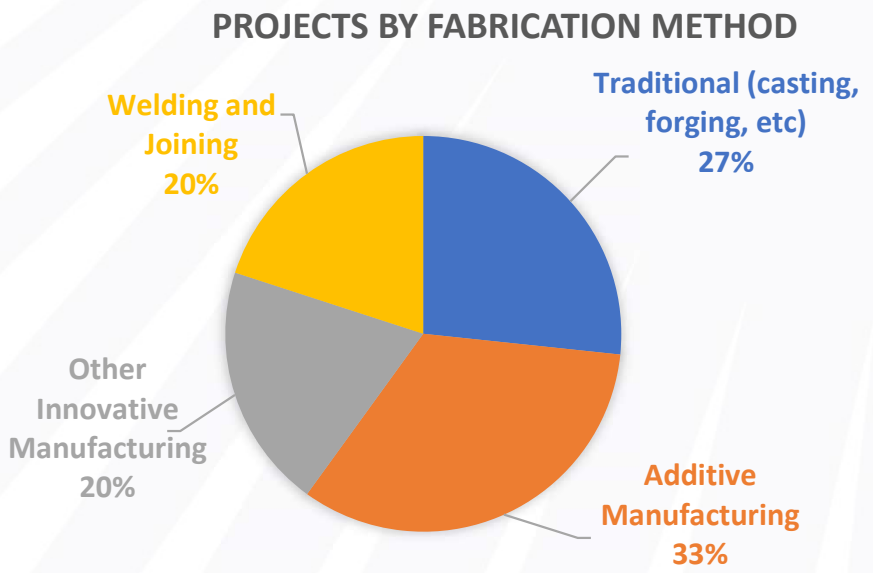


NSTTF SNL

CSP High Temperature Components and Characterization - Materials

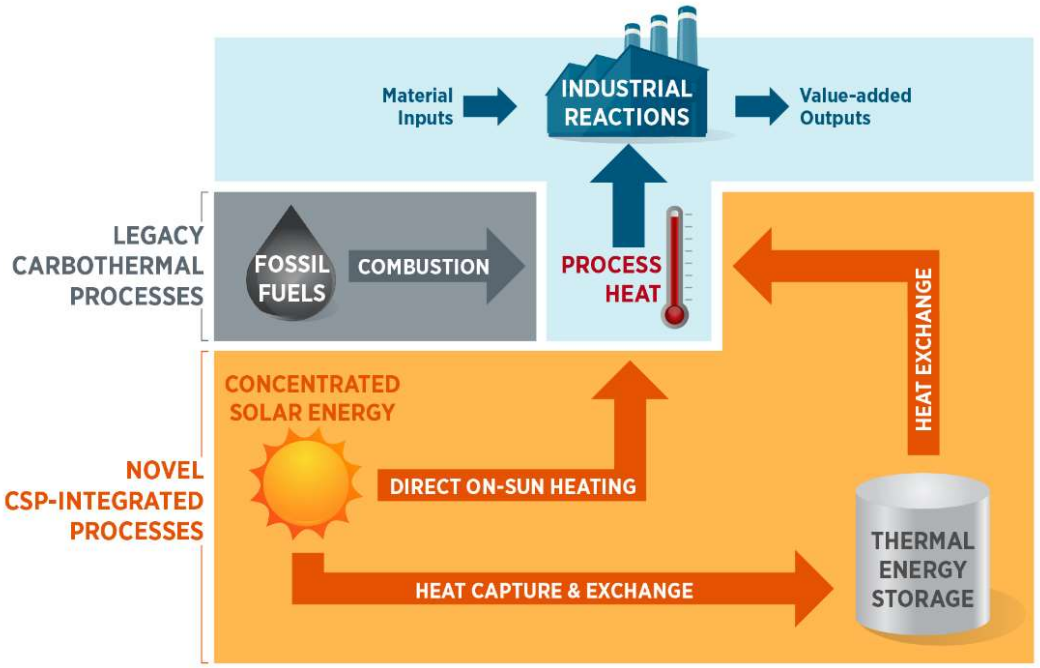
Materials see harsh service conditions that include temperature, pressure, chemical (salts, sCO_2), thermal cycling.





We seek continuous improvement in thermo-mechanical properties (Creep, Fatigue (low cycle), Creep-Fatigue, Tensile strength, Ultimate strength, Plastic deformation) and **chemical properties** (Corrosion, Erosion, (De)Carburization, Oxidation, liquid metal embrittlement)

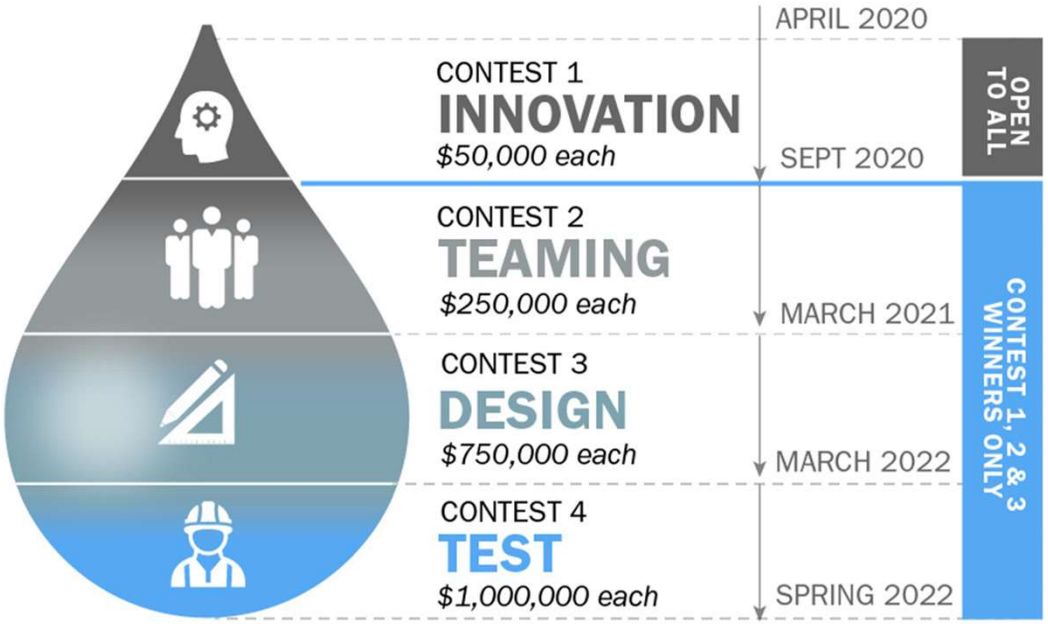
Solar Thermal for Decarbonization of Industrial Process Heat



Priority Research Areas

- Reduce the levelized cost of heat, **with thermal energy storage**, in temperature ranges of high priority to industrial processes
  - Roughly \$0.02/kWh$_{th}$ would be competitive with natural gas
- Improve the **thermal efficiency** of solar-thermal-coupled processes
- Develop long-duration, thermochemical storage of solar energy (i.e. **solar fuels** and chemical commodities)

American Made Challenges: Solar Desalination Prize



ROUND 1

- Currently in the Design Contest
- 8 Competitors remain

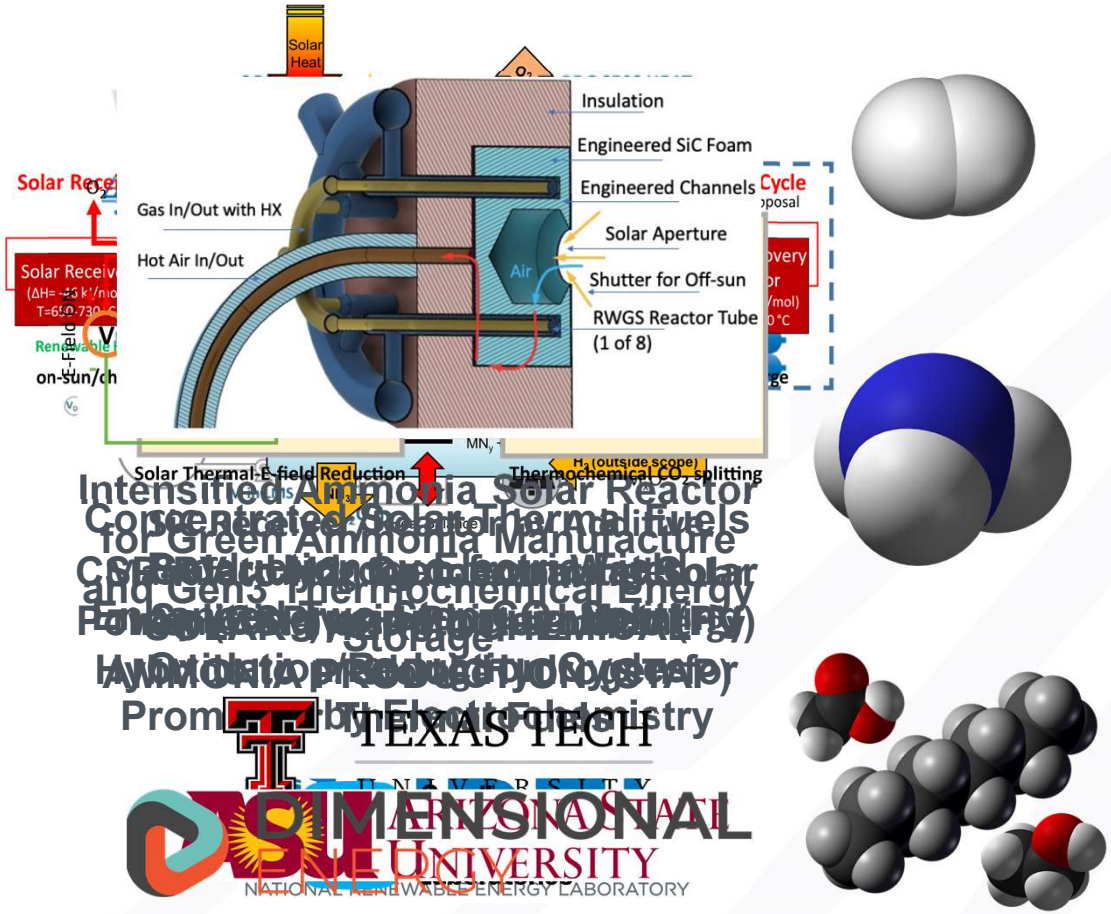
ROUND 2

- Currently in the Teaming Contest
- 12 Competitors remain

Accelerate commercialization of solar thermal desalination systems through successful demonstration of:

- Low-cost solar thermal collectors and thermal energy storage
- Innovative, highly efficient thermal desalination technologies

Solar Fuels for Energy Storage, Transport, Delivery



Hydrogen

- Amazing gravimetric energy density
- Chemical feedstock for NH_3, C_n fuels
- Multiple well-studied synthesis routes
- Abysmal volumetric energy density

Ammonia

- Acceptable energy density
- Plugs into legacy fertilizer infrastructure
- Potential hydrogen storage feedstock
- Unclear outlook as chemical fuel

Hydrocarbons

- High gravi/volumetric energy density
- Compatible w/ legacy infrastructure
- Requires CCS to reach net 0 emissions
- Product selectivity can be challenging

Funding Modalities for Targeted Impact

SIPS*

Seedling Projects

- Up to $400k over 18 months

Streamlined Application Process

- Reduced Application Steps, Documents, and Time

30 Projects Funded Since 2018

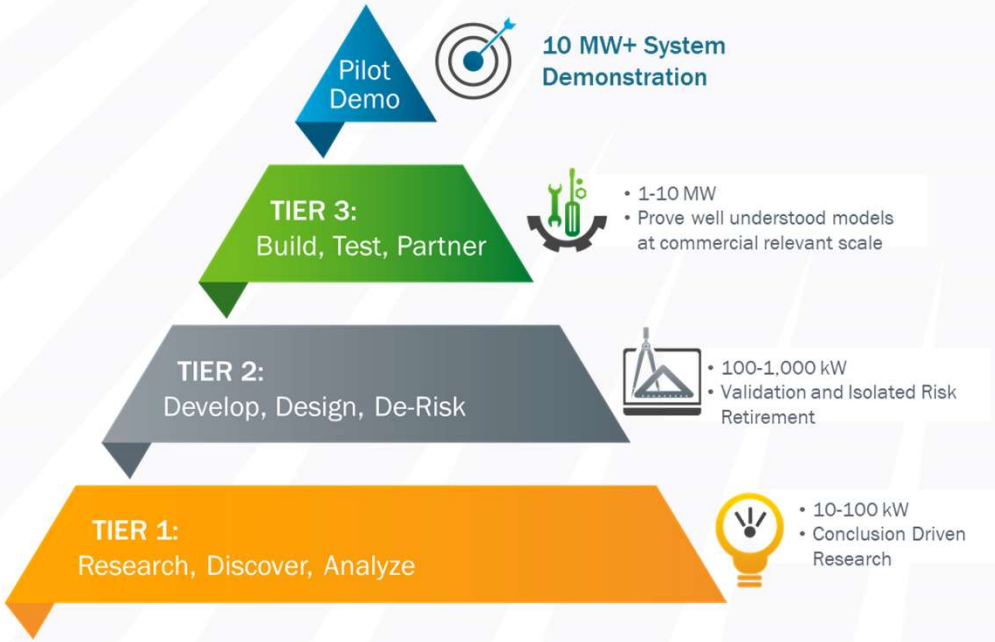
- Significantly increased the CSP R&D Community
- Increased Diversity of Institutions and Researchers

Strategic Importance

- Solutions for unique CSP frameworks, or
- Innovate to solve known programmatic gaps

*Small Innovative Projects in Solar

SOLAR** Tiers



**Scalable Outputs for Leveraging Advanced Research

Thank You!

The SETO newsletter highlights the key activities, events, funding opportunities, and publications that the solar office has funded.



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