# Planning and Operation of A Decarbonized Grid
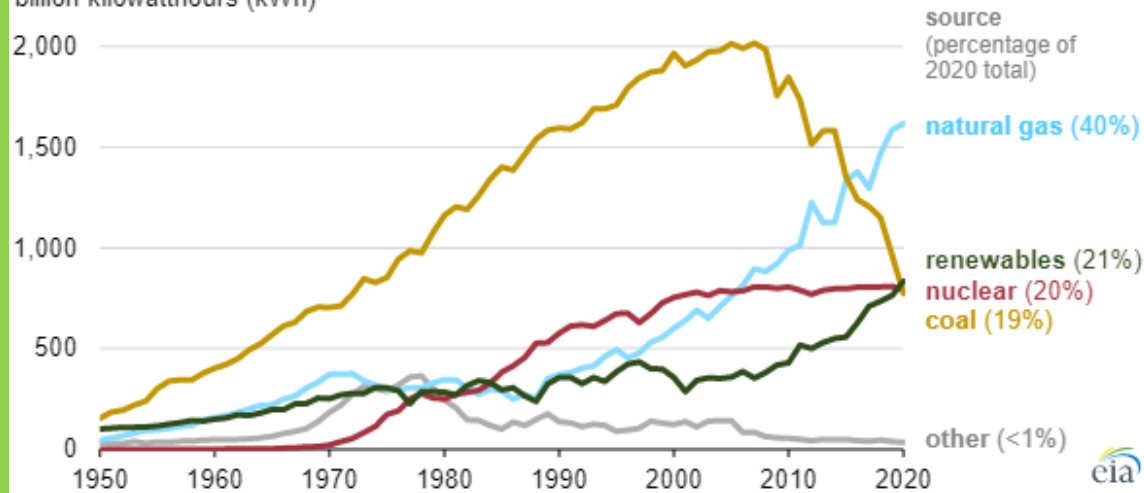
## Challenges and Opportunities

Guohui Yuan, Program Manager

Presented at SETO Workshop: Fast Time-Scale Modeling of Power Systems with Distributed Solar, Nov. 16-17, 2021

energy.gov/solar-office

# Energy System Transformation

## Long Term Strategy of the U.S.

- Pathways to Net Zero GHG Emissions by 2050 (published November 2021)
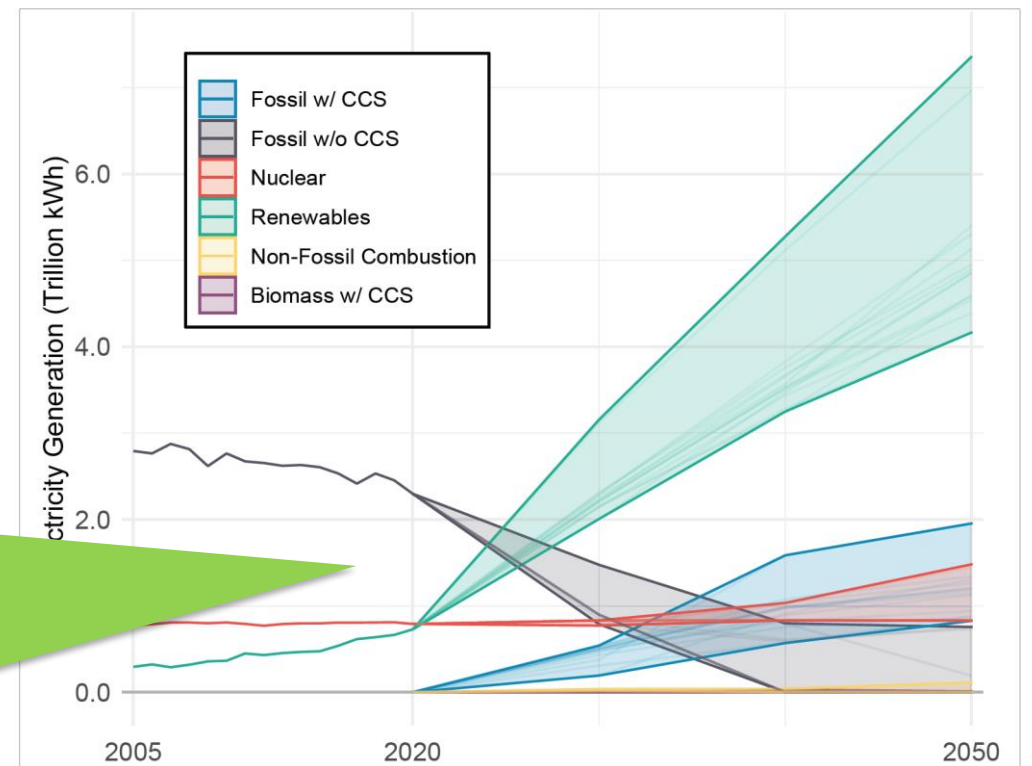
Renewables became the second-most prevalent U.S. electricity source in 2020 (EIA)



Annual U.S. electricity generation from all sectors (1950–2020)
billion kilowatthours (kWh)

source (percentage of 2020 total)

natural gas (40%)
renewables (21%)
nuclear (20%)
coal (19%)
other (<1%)



Electricity Generation (Trillion kWh)

Legend:
- Fossil w/ CCS
- Fossil w/o CCS
- Nuclear
- Renewables
- Non-Fossil Combustion
- Biomass w/ CCS

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# Solar Energy Plays a Critical Role in Decarbonization

## Q2/2021 data snapshot (SEIA)

| | |
|---|---|
| Installed Solar Capacity | 109 GW |
| Price decline in last 5 years | 36% |
| Annual Growth in last 10 years | 42% |
| Fraction of Electricity Generation | 4% |
| **Solar Energy Potential by 2035*** | **40%** |

*DOE Solar Futures Study*
*https://www.energy.gov/eere/solar/solar-futures-study*

### Cumulative U.S. Solar Installations
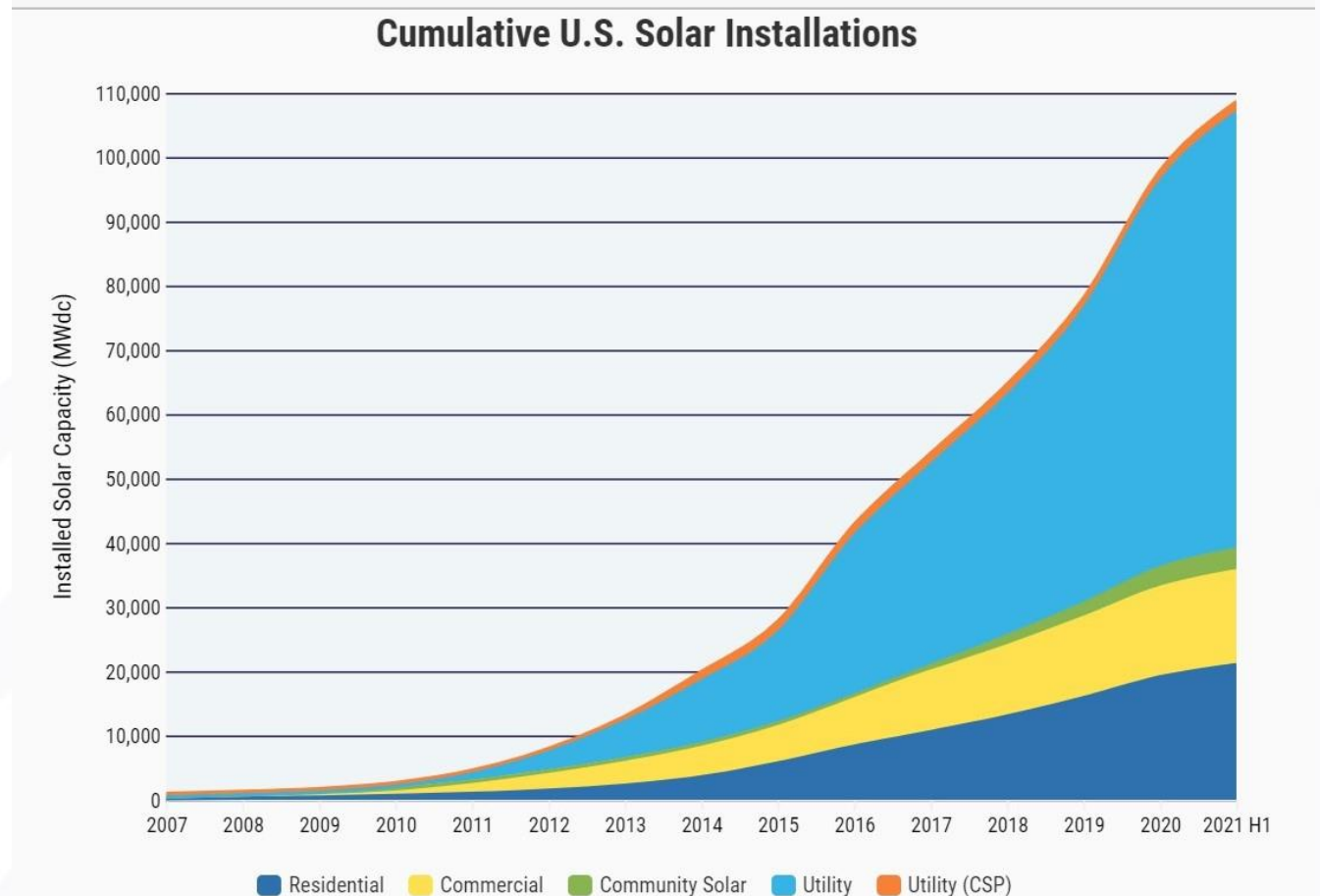


Source: SEIA/Wood Mackenzie Power & Renewables U.S. Solar Market Insight 2021 Q3

Wood Mackenzie POWER & RENEWABLES

SEIA Solar Energy Industries Association®

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# Many Challenges for Solar Grid Integration

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



Hourly Average Breakdown of Total Production By Resource Type

This graph depicts the production of various generating resources across the day.



Hourly Average Breakdown of Renewable Resources

This graph shows the production of various types of renewable generation across the day.
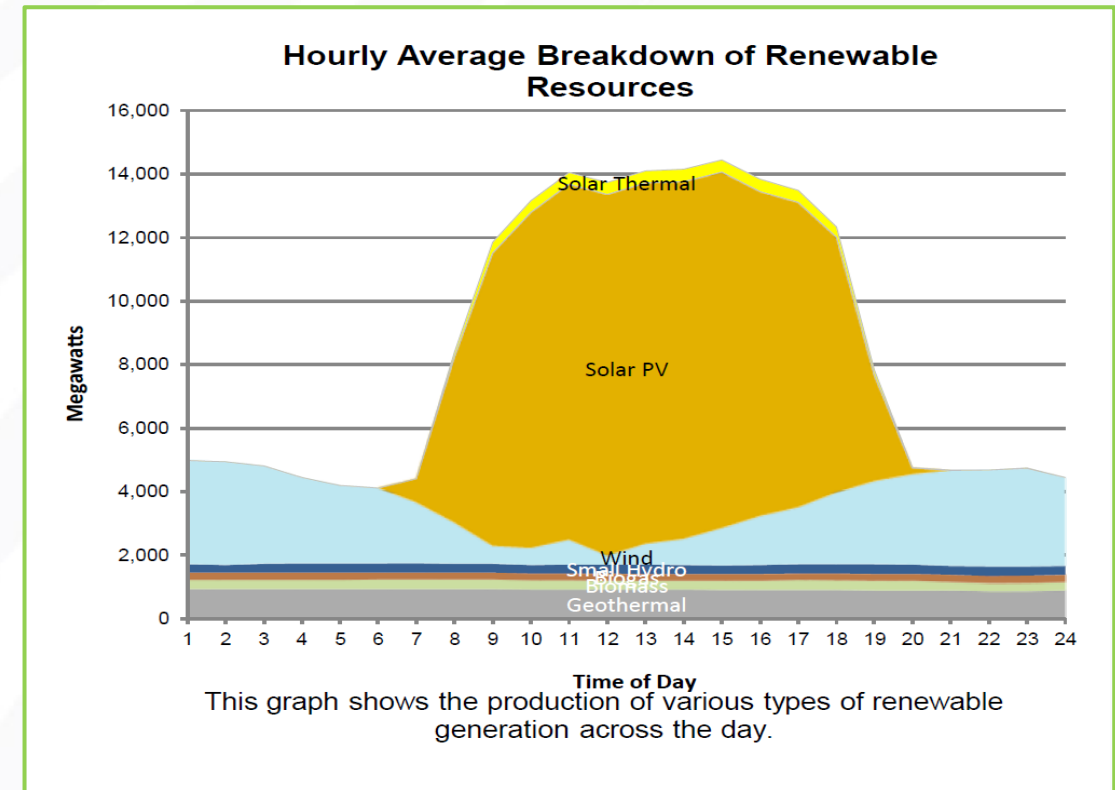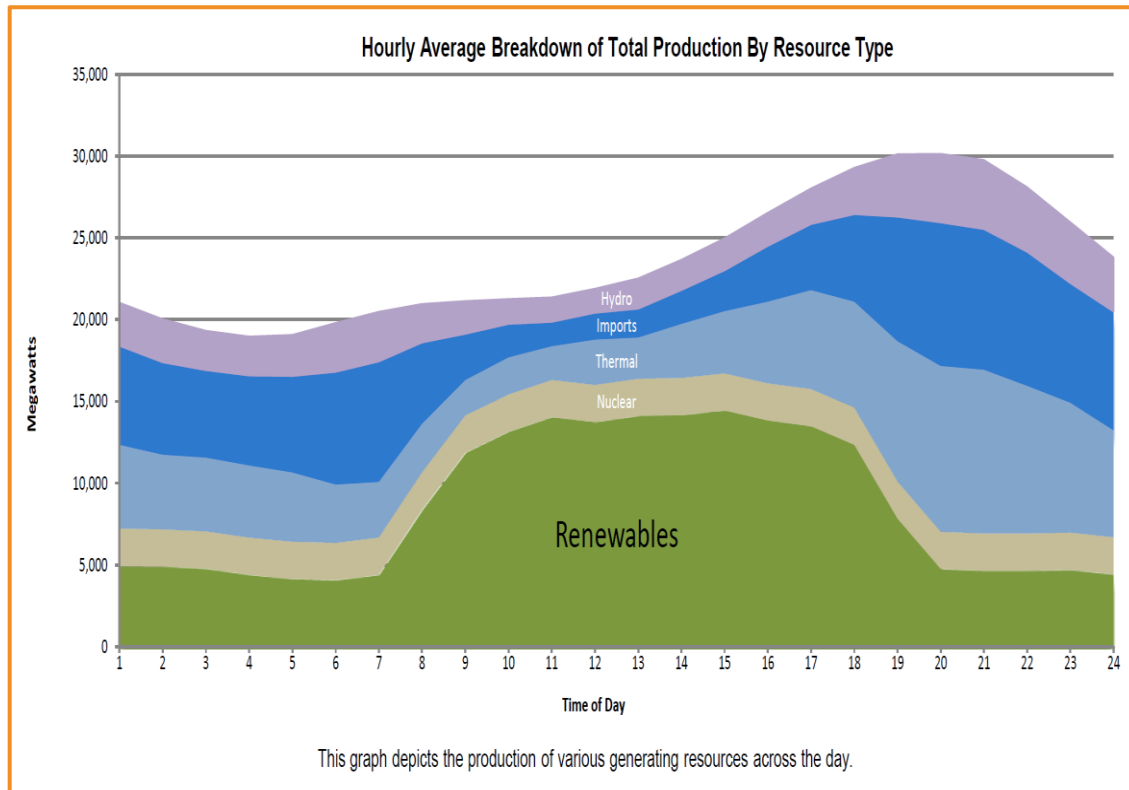
# Many Challenges for Solar Grid Integration (Continue)

| 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
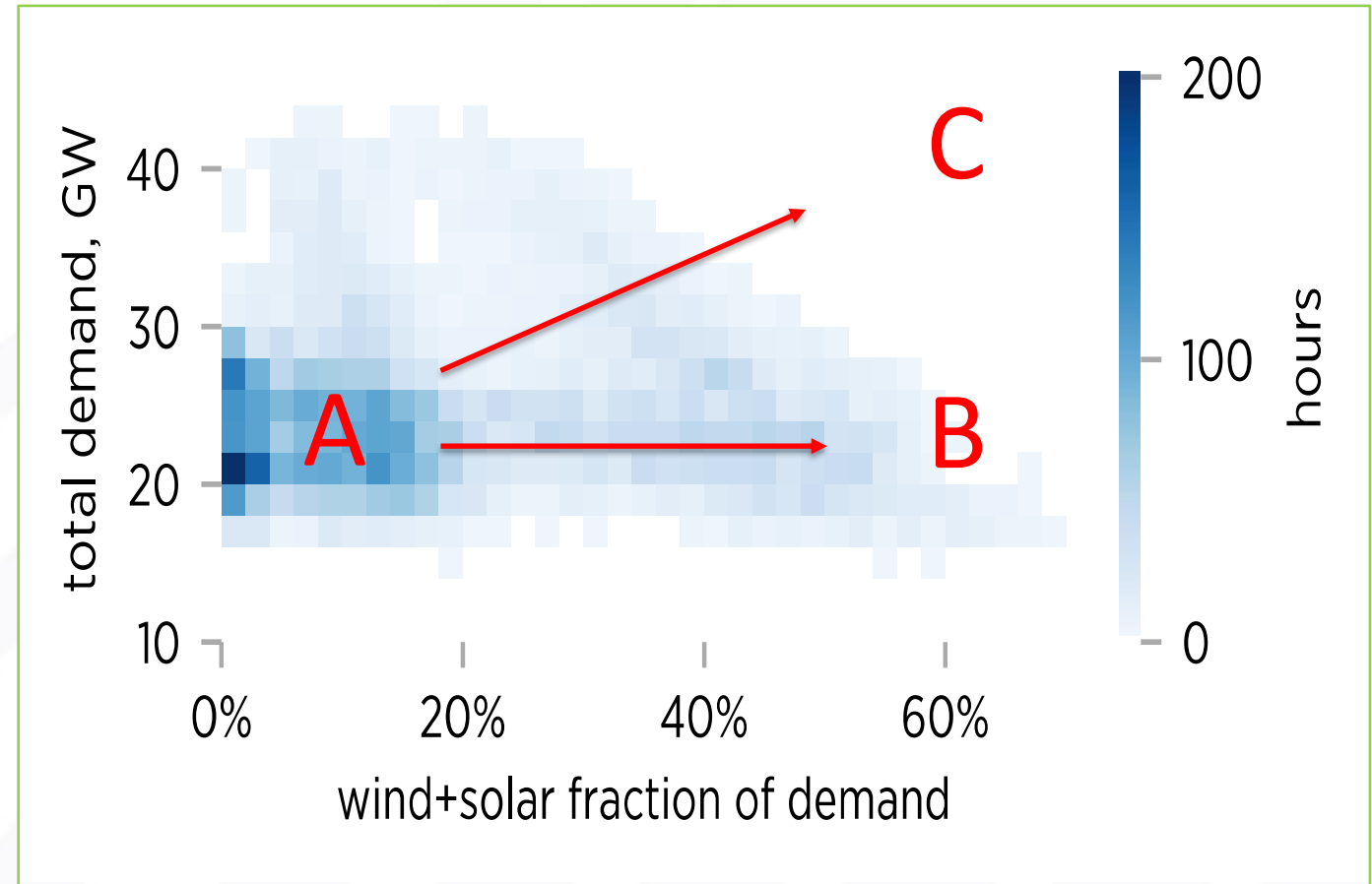


*Annual wind/solar profile (CAISO 2019, EIA OpenData)*

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# DOE Solar Energy Technologies Office (SETO) Overview

## MISSION

We accelerate the **advancement** and **deployment of solar technology** in support of an **equitable** transition to a **decarbonized energy system by 2050**, starting with a decarbonized power sector by 2035.

## WHAT WE DO

**Advance solar technology** and drive soft cost reduction to make solar **affordable** and **accessible** for all Americans

Enable solar to **support grid reliability** and pair with storage to provide new options for **community resilience**

Support **job growth**, **manufacturing**, and the **circular economy** in a wide range of applications

# SETO Systems Integration (SI) Program

The Systems Integration (SI) subprogram supports early-stage research, development, and demonstration (RD&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.
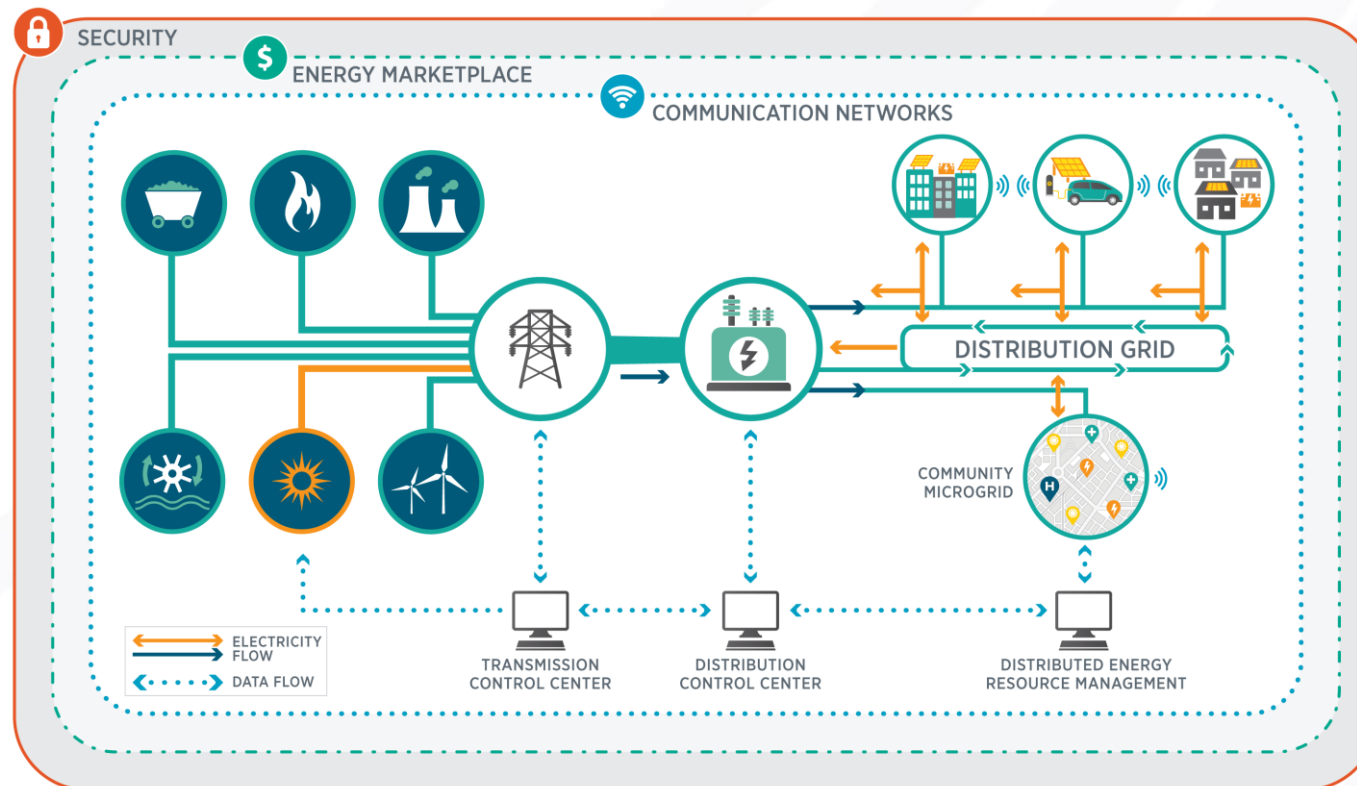
# GMI – DOE-Wide Collaboration



DOE's Grid Modernization Laboratory Consortium – 14 National Labs – 100+ Partners
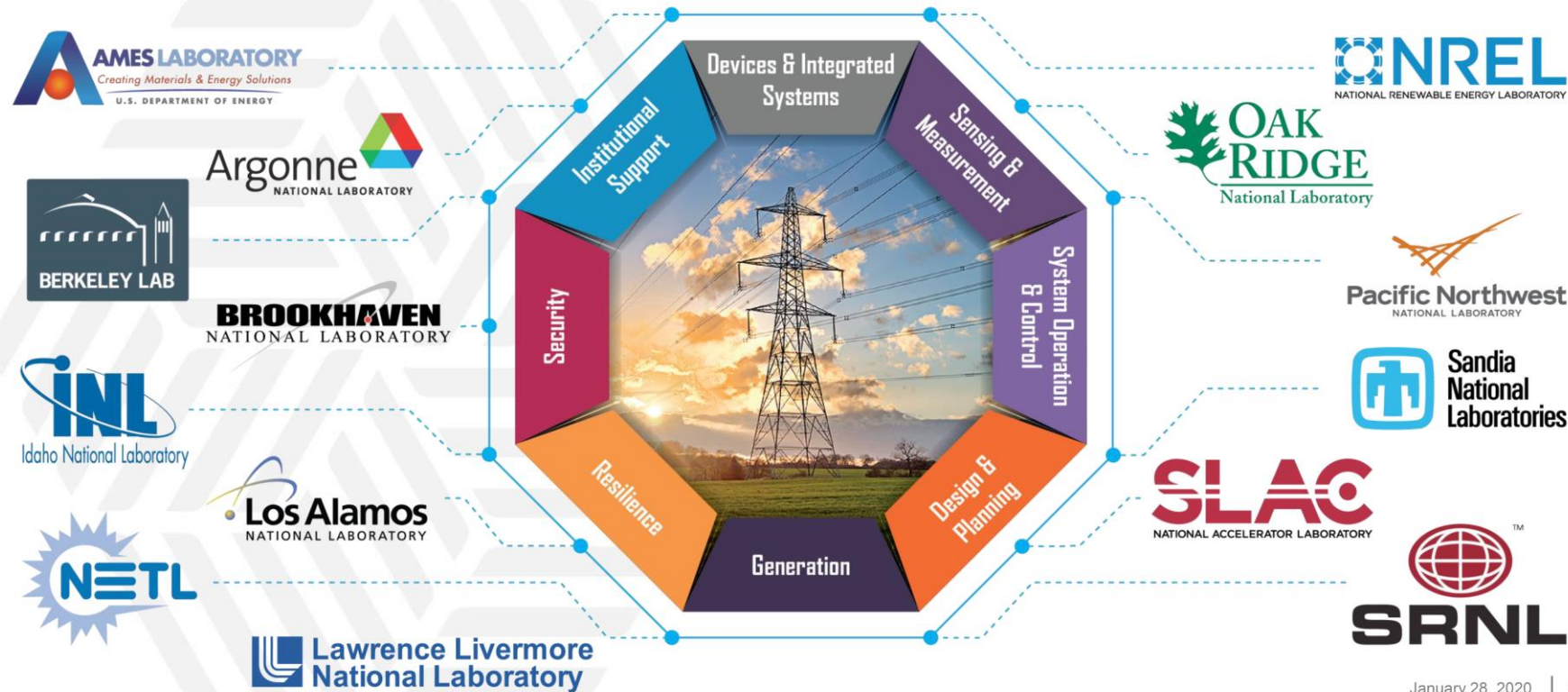
# SETO System Integration Key Research Areas

## ~$50M annual budget, ~90 active projects

| System Planning | System Operation | DER Integration & Resilience | Enabling Technologies |
|---|---|---|---|
| • Power system modeling<br>• Solar & load forecasting<br>• Production cost modeling<br>• Integration studies<br>• Codes and standards | • RT situation awareness<br>• Power flow control<br>• System protection<br>• Grid services<br>• Cybersecurity | • Community microgrids<br>• BTM DERs<br>• Resilience and cybersecurity<br>• Verification and validation<br>• Regional partnerships | • Power electronics<br>• Energy storage<br>• Data analytics & AI/ML<br>• Sensing and communication<br>• PHIL testing |

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# Solar Generation Variability and Uncertainty

Solar Irradiance Data (GHI, DNI):

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



**Sample measurements (1 min)**

Livermore, CA

Mayaguez, PR

Oahu, HI

Sacramento, CA

San Diego, CA

day of week
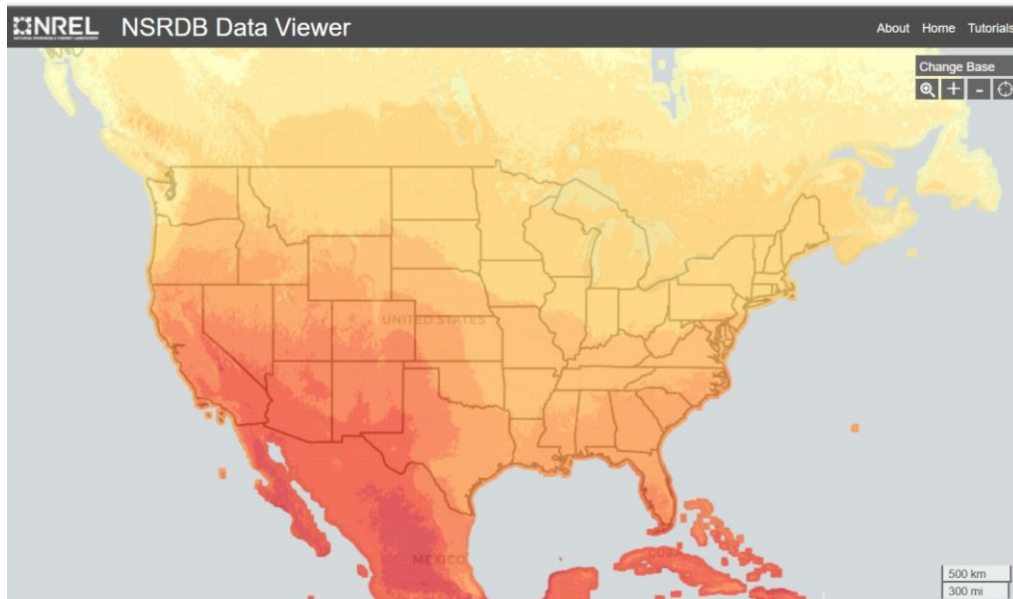


*2019 Annual Mean of GHI from NSRDB (2km x 2km, 5 min, Terabytes)* Home - NSRDB (nrel.gov)
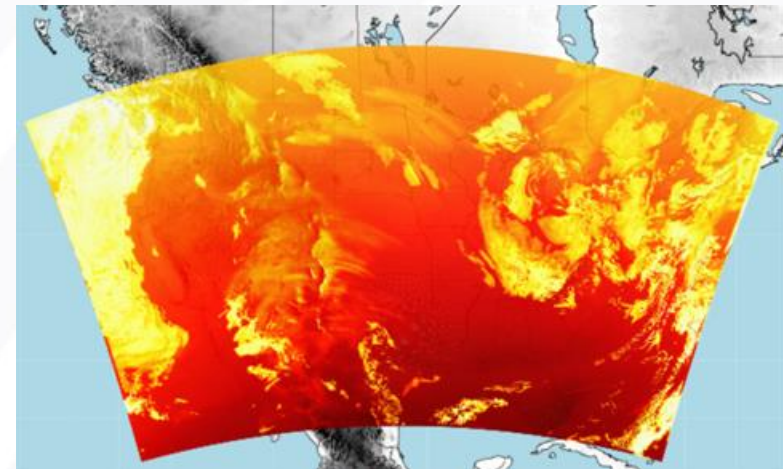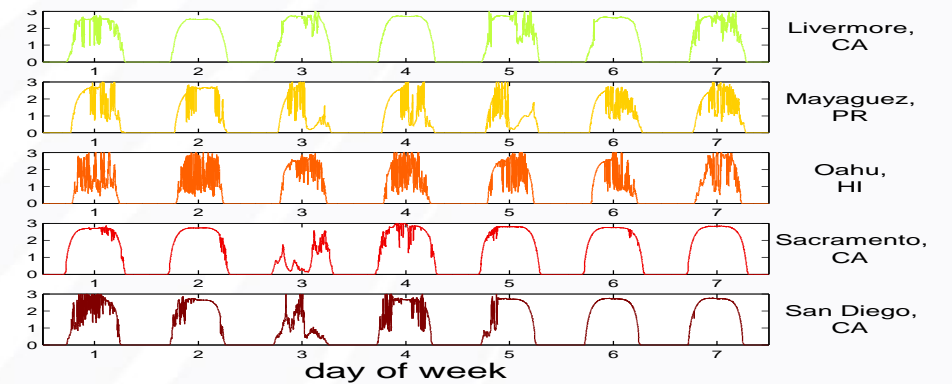


WRF-Solar® | NCAR Research Applications Laboratory | RAL (ucar.edu) **Run on HPC**

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# Autonomous Energy Systems (NREL)

# UNIFI Grid-Forming Technology Consortium

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



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

Within the left diagram:
- research & development
- demonstration & commercialization
- outreach & training
- future grids with GFM IBRs
- stakeholders: national labs, universities, industry, utilities, system operators

**unifi will unify**
- New & Old (GFM+other IBRs, machines)
- Local & Global (controls)
- Slow & Fast (timescales of operation)
- Big & Small (inverters & aggregations)
- Solar, Wind, & Storage (technologies)



☐ Project Co-leads, ● Project Team

**National Labs**
- *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**
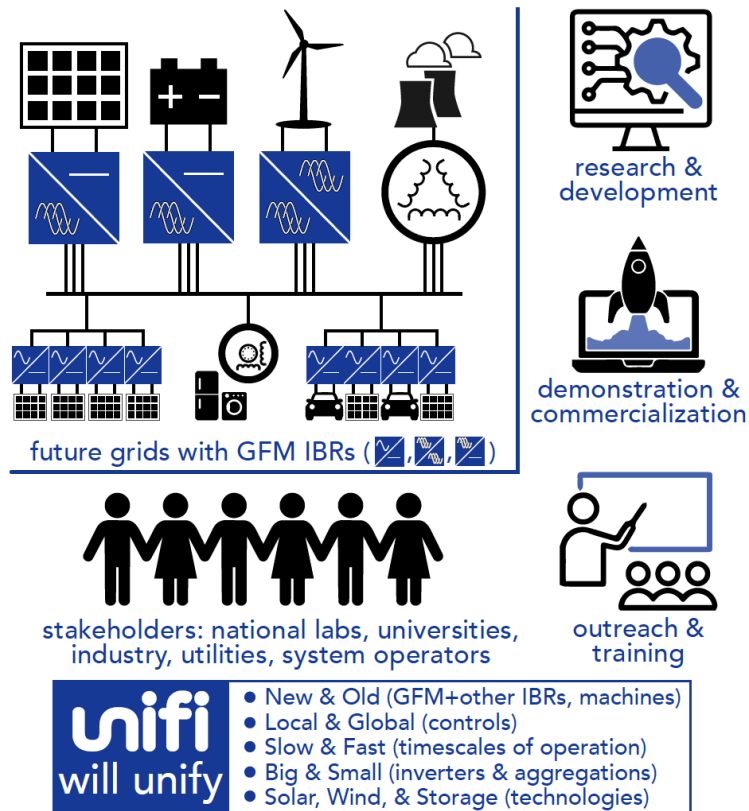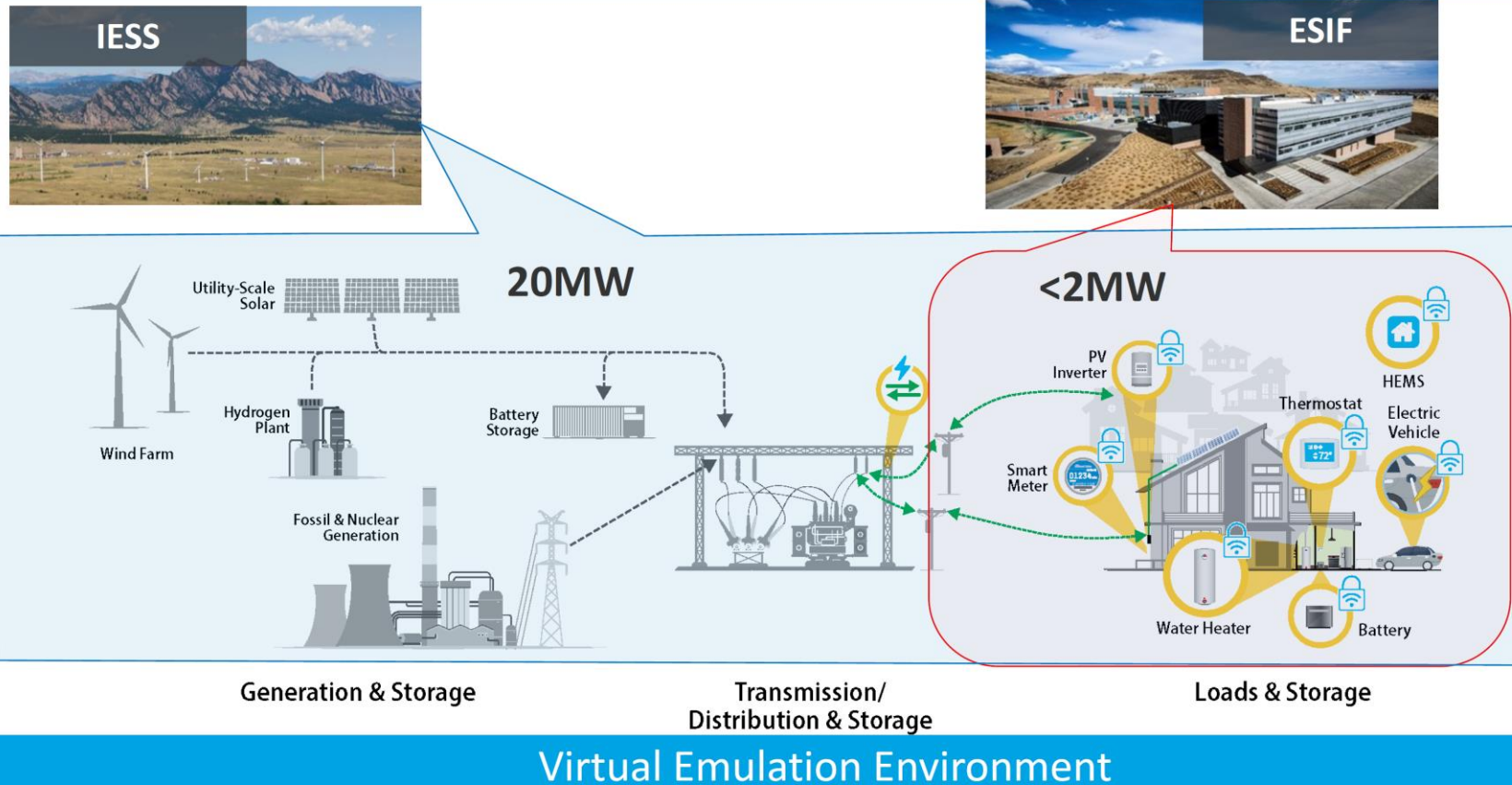- *University of Washington (UW)* — B. Johnson
- *University of Minnesota (UMN)* — S. Dhople
- *Georgia Tech (GT)* — D. Divan
- *Arizona State University (ASU)* — V. Vittal, R. Ayyanar
- *North Carolina State University (NCSU)* — I. Husain, S. Lukic, D. Lubkeman
- *University of Alaska Fairbanks (UAF)* — 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**



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# Investing in World Class Test Facility



*(Courtesy: Barry Mather, NREL)*

# Modeling Needs for Energy Transformation

- Generation resource and load data and forecasting

  - Data inputs from various types of sensors

  - Solar resources (including BTM) and load forecasts

  - High spatiotemporal resolution

- Physical system multi-scale modeling

  - Power electronic modeling

  - Power system modeling (steady state, transient stability, and dynamic behaviors)

  - Co-simulation of T + D + communication + DER

  - CHIL and PHIL modeling

- Multi-domain modeling

  - Interdependence of infrastructures (electricity, gas, transportation, communication, cyber)

  - Market and technoeconomic studies for renewable integration

  - DER control and consumer behaviors

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# Infrastructure Bill Clean Energy Highlights

- Total more than $62 billion for the U.S. Department of Energy (DOE)

- The creation of a new Office of Clean Energy Demonstrations at the Department of Energy which includes $21.5 billion for clean energy demonstration projects.

- $8 billion for power grid resilience and other electricity projects, plus provisions to backstop permitting authority for interregional transmission lines.

- $27.8 billion for carbon capture, hydrogen and direct air capture efforts, plus $7.7 billion for critical minerals.

*[DOE Fact Sheet: The Bipartisan Infrastructure Deal Will Deliver For American Workers, Families and Usher in the Clean Energy Future | Department of Energy](#)*

# Questions?

- Contact me, Guohui.Yuan@ee.doe.gov