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

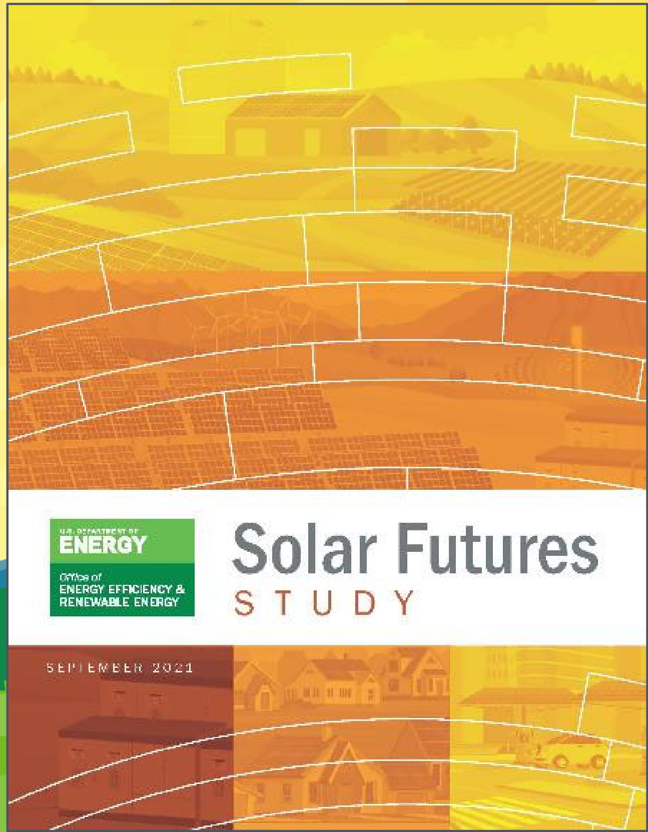
Concentrating Solar-thermal for industrial applications

Matthew Bauer, Acting Program Manager

Industrial Processes Emissions Reduction (IPER) Technology Workshop
March 2, 2023

Driving Toward Administration Decarbonization Goals

- **Reduce hardware and soft costs** of solar electricity **for all Americans** to enable an affordable carbon-free power sector by 2035.
- Enable inverter-based technologies to provide essential grid services and black start capabilities while demonstrating the **reliable, resilient and secure operation of a 100% clean energy grid**.
- **Accelerate solar deployment and associated job growth** by opening new markets, reducing regulatory barriers, providing workforce training, and growing U.S. manufacturing.
- **Center energy justice** by reducing environmental impacts, removing barriers to equitable solar access, and supporting a diverse and inclusive workforce.
- **Support a decarbonized industrial sector** with advanced concentrating solar-thermal technologies and develop affordable renewable fuels produced by solar energy.



https://www.energy.gov/eere/solar/solar-futures-study

Applications of Solar-Thermal Energy

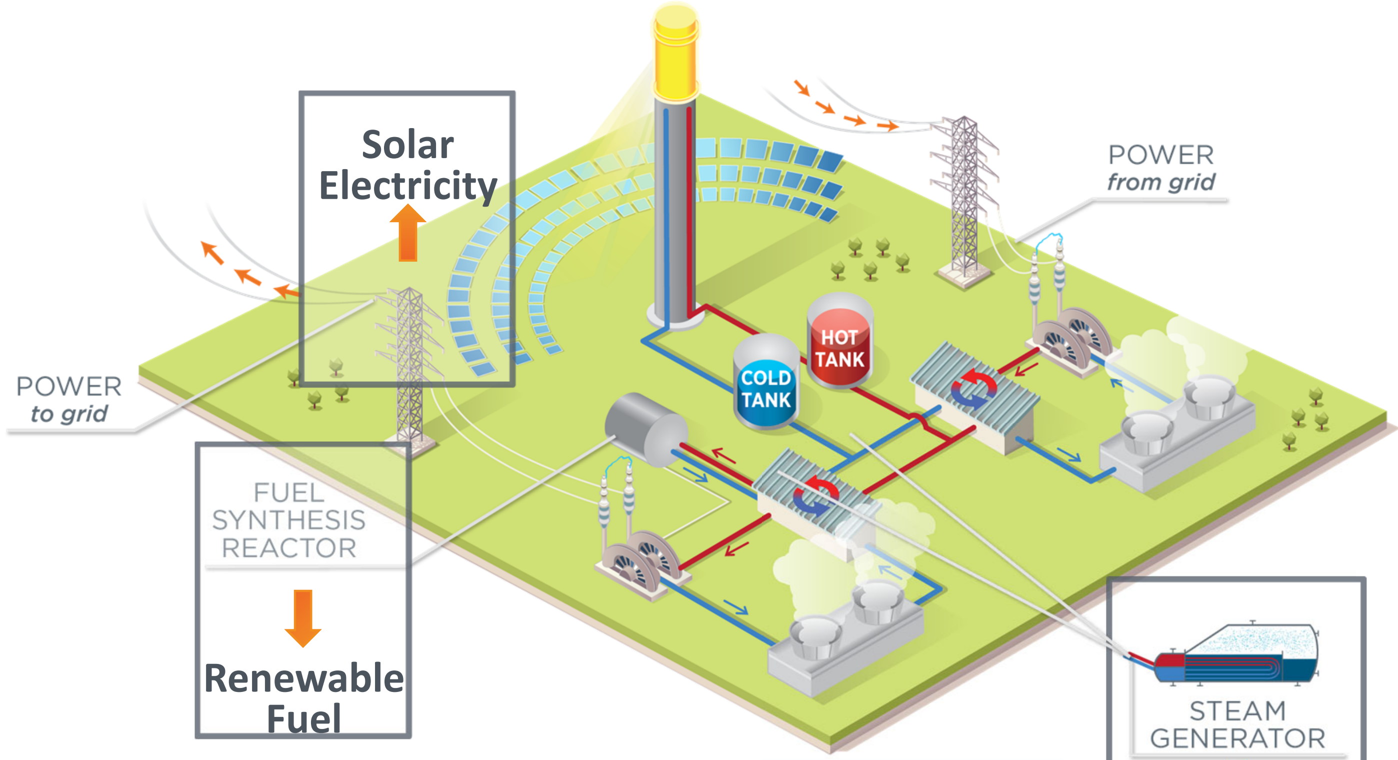
Oil-Based Troughs with steam rankine cycle (390 °C)

↓

Molten Salt Towers with steam rankine cycle (565 °C)

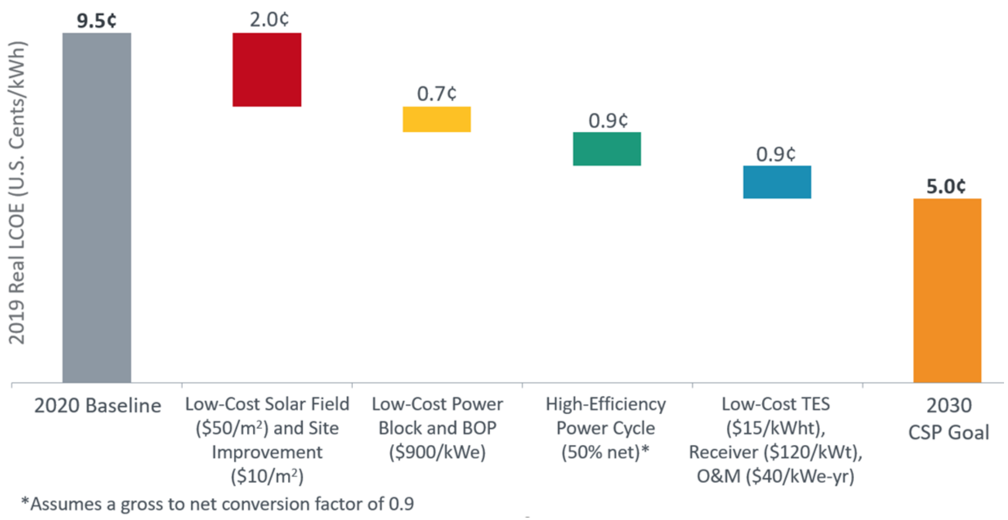
↓

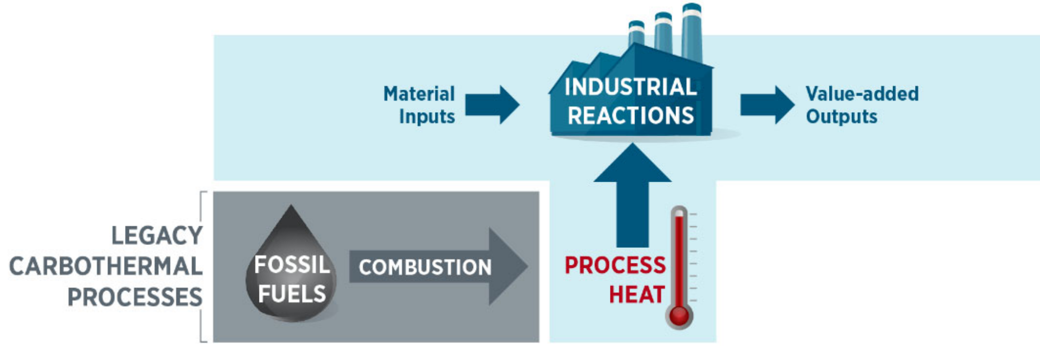
'Gen 3 CSP': Novel Heat Transfer Media with advanced power cycle (>700 °C)



Approximately **7 GW_e of CSP** is globally operating commercially

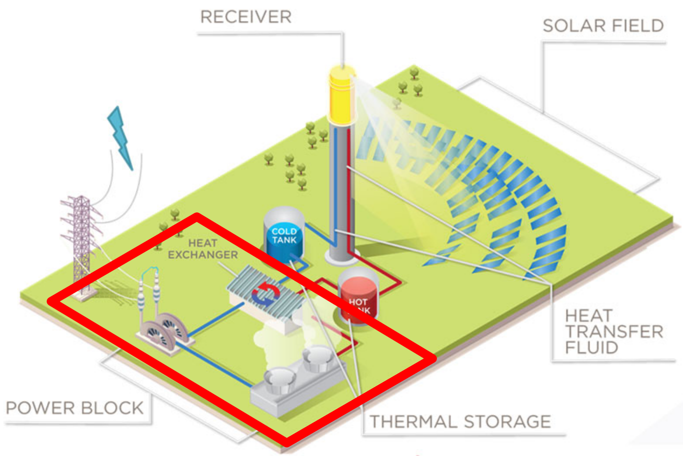
CSP Goals

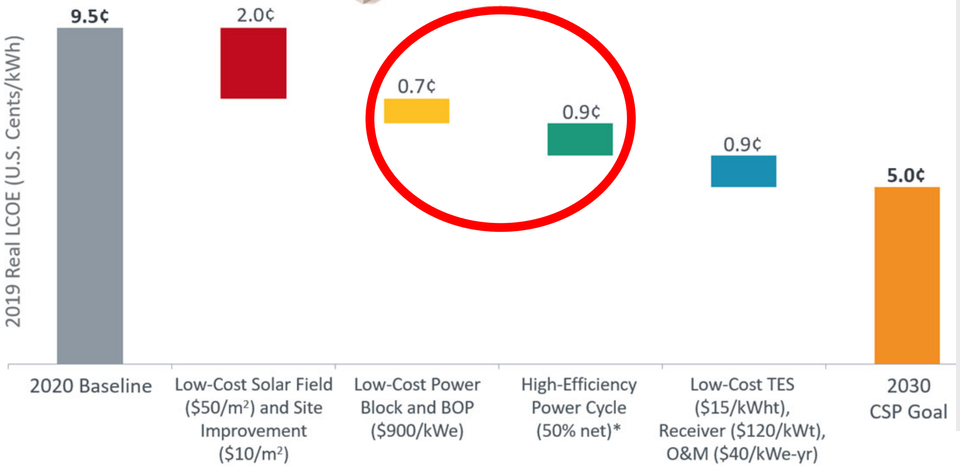




- Achieve LCOE goal through high efficiency power cycles operating at > 700 °C
- Reduce the levelized cost of heat, with thermal energy storage, to $\$0.02/kWh_{th}$, across a range of temperatures relevant to industrial processes

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

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

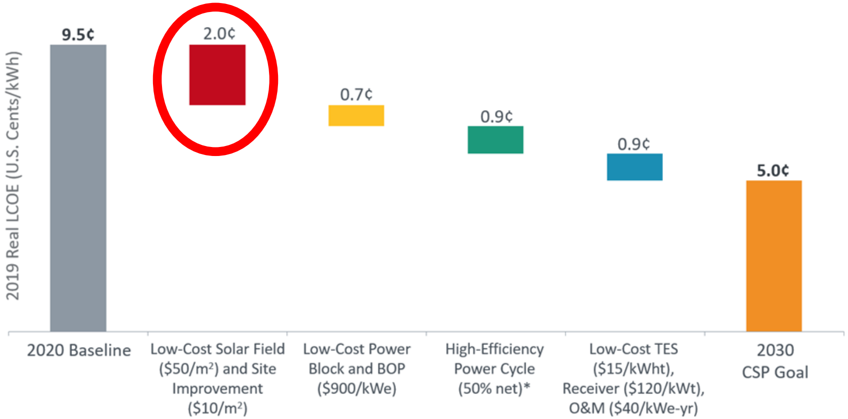
TESTBED

- 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

CSP Goals



*Assumes a gross to net conversion factor of 0.9

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

Objectives of the $25 million consortium:

- Respond to gaps in published Roadmap
  - https://www.nrel.gov/docs/fy22osti/83041.pdf
- Develop key testing capabilities to validate and optimize industrial heliostat technologies
- Fund collaborative research on heliostat innovation
- Form U.S. centers of excellence focused on heliostat technology

NREL Transforming ENERGY

ASTRI Australian Solar Thermal Research Institute

Sandia National Laboratories

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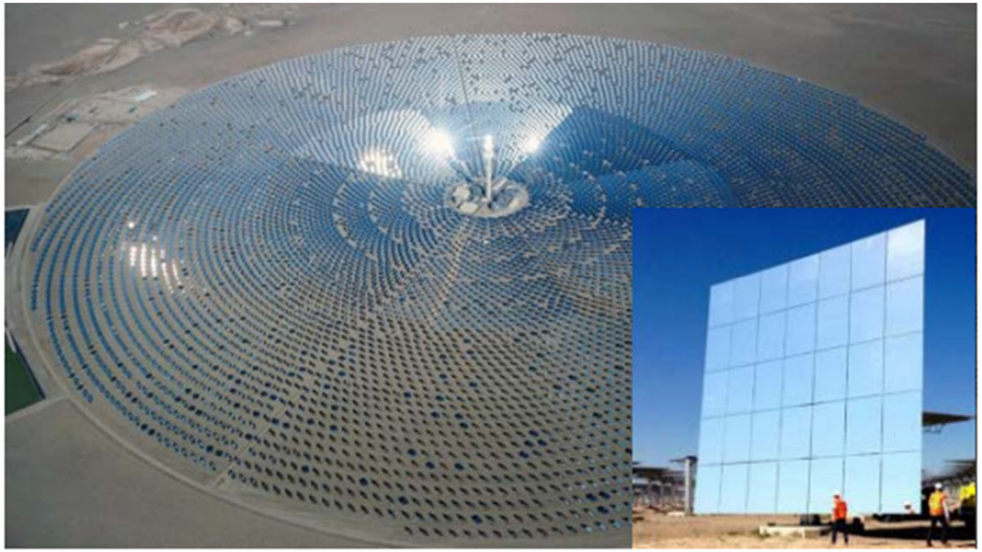
Heliostat Consortium: Roadmap Gap Analysis



- Technoeconomic Sensitivities
- Metrology and Standards
- Components and Controls
- Advanced Manufacturing
- Resource, Training, and Education
- Field Deployment

Special Topics

- Wind Loading
- Soiling

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

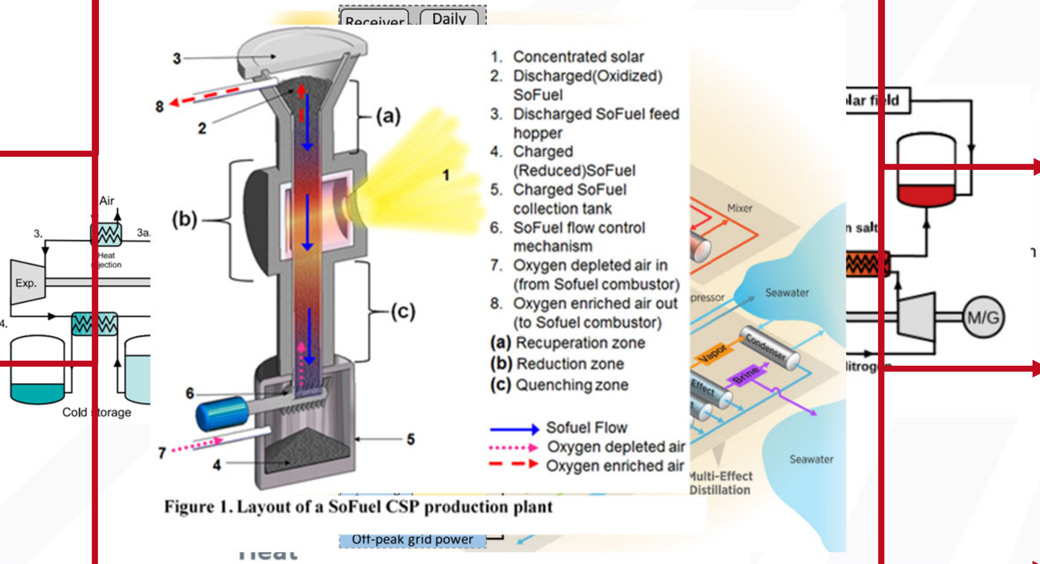


Figure 1. Layout of a SoFuel CSP production plant

Ellen Stechel, "Economic ... Energy Storage for Advanced ..."

James Klausner, "Solid State Solar Thermochemical Fuel (SoFuel) for Long Duration Storage"

... et al. "Overview and design ... Gen 3 Particle Pilot Plant (G3P3)." *AIP Conference Proceedings*. Vol. 2303. No. 1. AIP Publishing LLC, 2020.

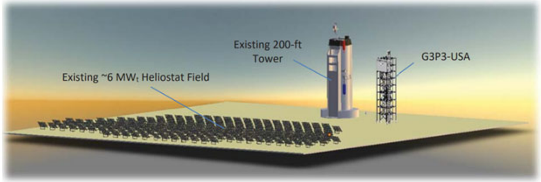
... supercritical carbon dioxide Brayton cycle." *Desalination* 459 (2019): 20-33.

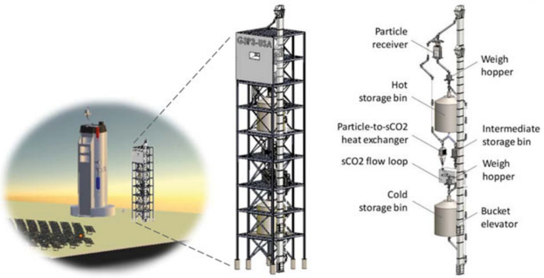
Gen3 CSP: Pathway Selection

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		





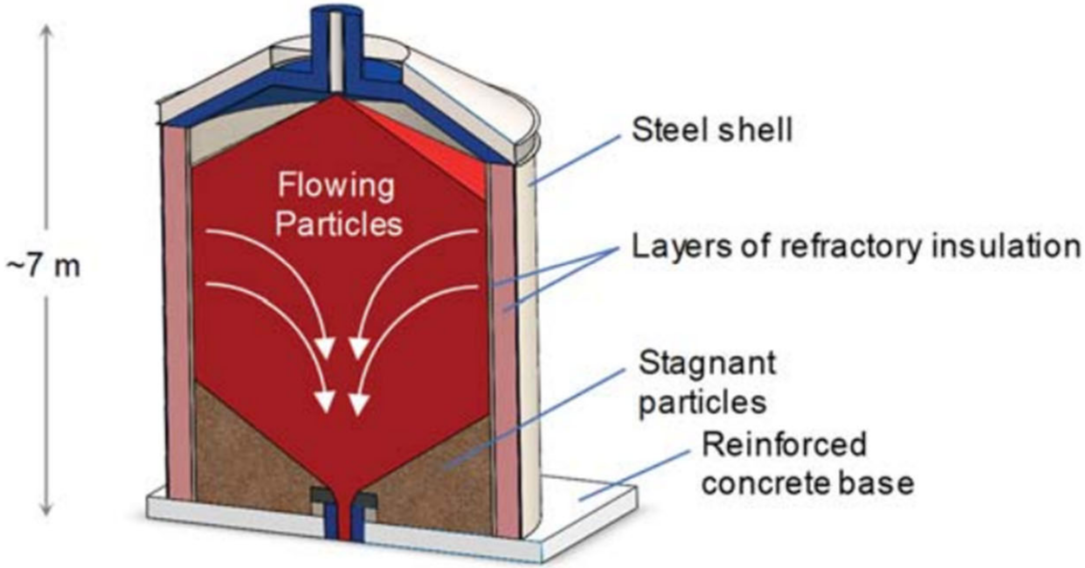
Strengths:

- 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

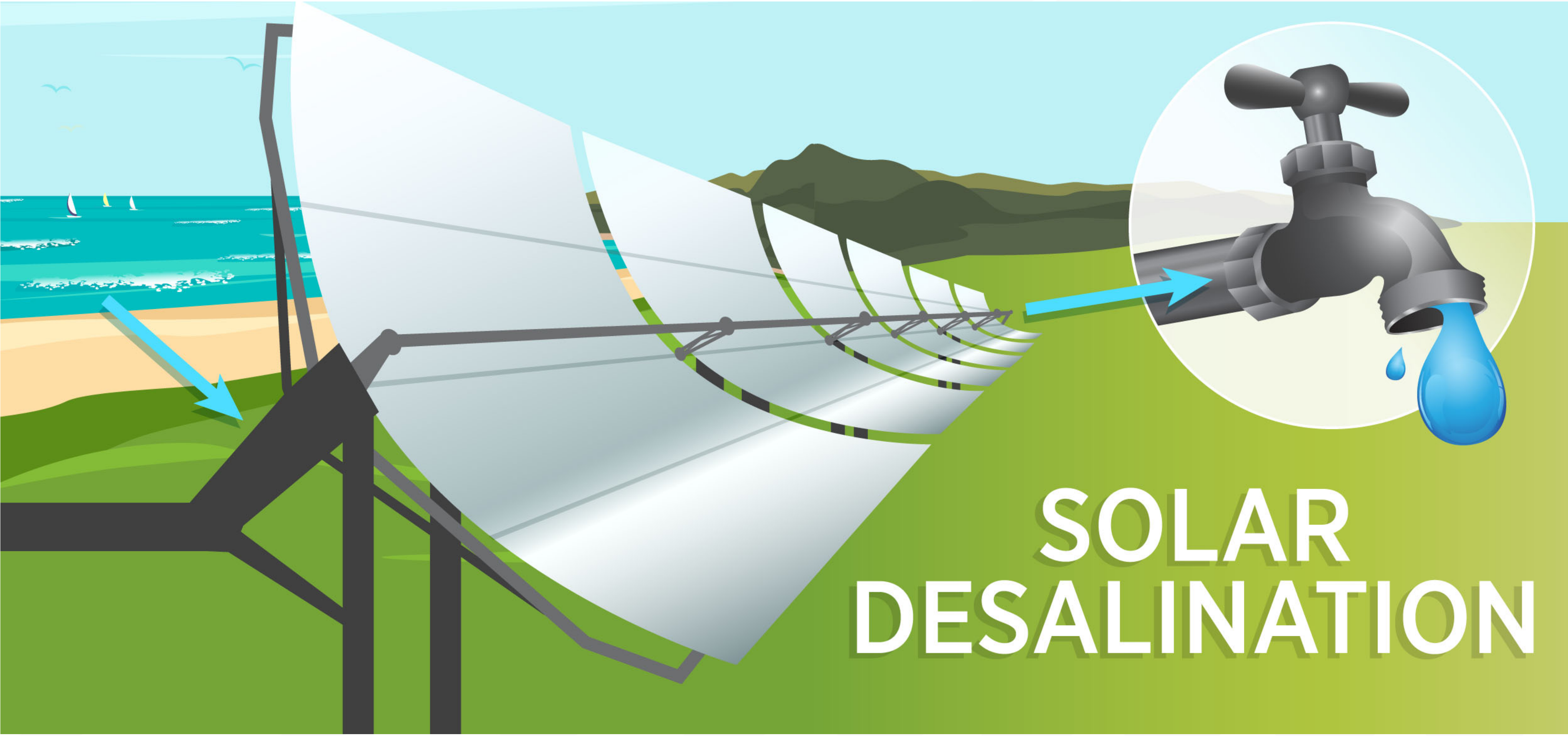
Particles for Gen3 CSP and Beyond



CARBO HSP 40/70	
Composition	Al_2O_3 (83%), SiO_2 (5%), Fe_2O_3 (7%), TiO_2 (3.5%)
Median particle diameter (µm)	~350
Specific gravity	3.6
Bulk density (kg/m^3)	~2,000
Roundness	~0.9
Sphericity	~0.9
Specific heat (J/kg-K) at 700°C	1,250
Bed solar absorptance	0.93
Bed thermal emittance	0.86

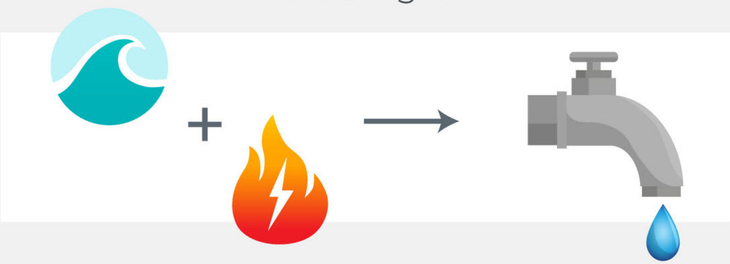
Clifford K. Ho, Kevin J. Albrecht, Lindsey Yue, Brantley Mills, Jeremy Sment, Joshua Christian, and Matthew Carlson , "Overview and design basis for the Gen 3 Particle Pilot Plant (G3P3)", AIP Conference Proceedings 2303, 030020 (2020) https://doi.org/10.1063/5.0029216

Solar Desalination Funding Program 2017

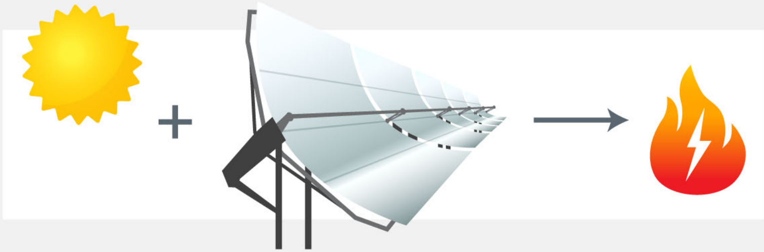


Solar Desalination Funding Program 2017

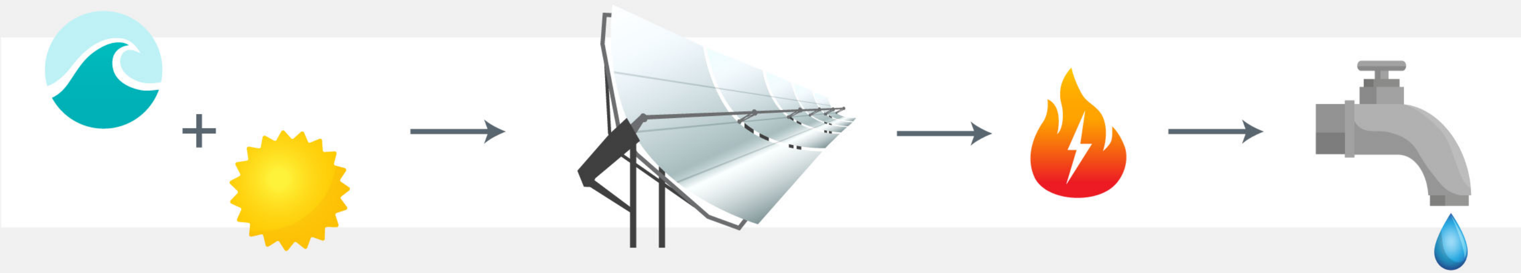
TOPIC AREA 1:
Innovations in thermal desalination technologies



TOPIC AREA 2:
Low-cost solar thermal heat



TOPIC AREA 3: Integrated solar desalination systems

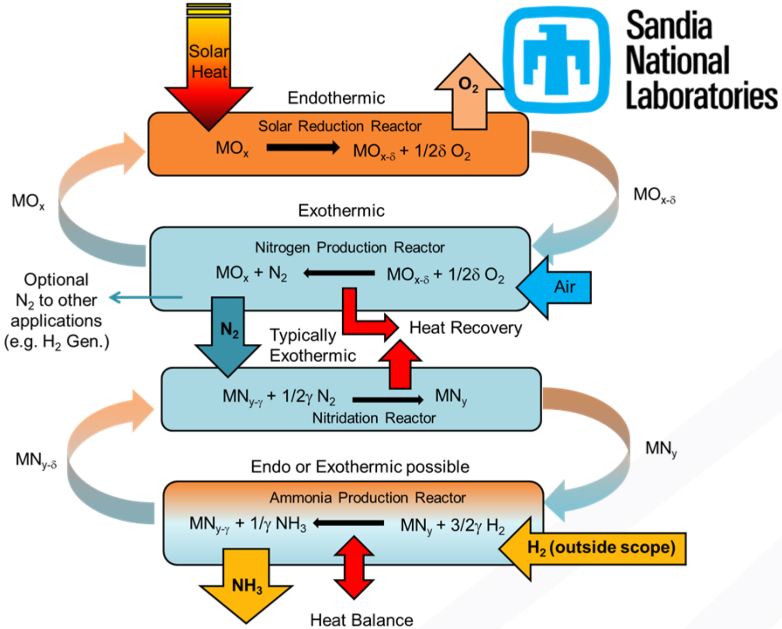


TOPIC AREA 4: Analysis for solar thermal desalination

Solar Desalination Funding Program 2017

- **Natural Energy Laboratory of Hawaii Authority (NEHLA)**
  Hawaii Ocean Science and Technology Park
- "Hawaii Solar Desalination Project"
- 2 MW Trough Solar Field Coupled with Forward Osmosis
- Capstone Demonstration Testing Ongoing

Hydrogen and Solar Fuels Related R&D



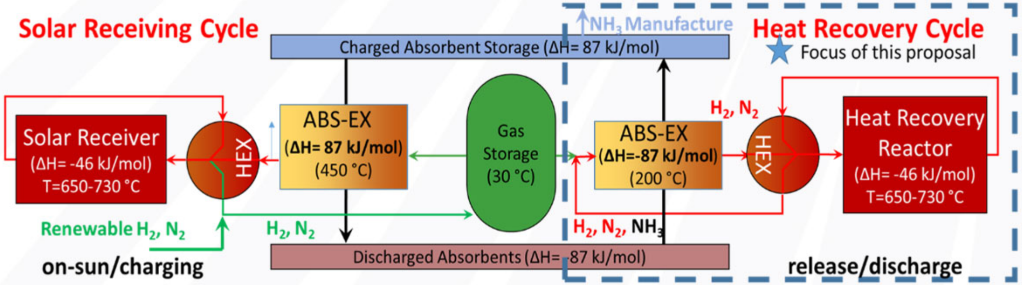
Solar Thermochemical Ammonia Production (STAP)

PI: Andrea Ambrosini

Bush, H. E., Nguyen, N. P., Farr, T., Loutzenhiser, P. G., & Ambrosini, A. (2021). Air separation via a two-step solar thermochemical cycle based on (Ba, La) xSr1-xFeO3-δ: Thermodynamic analysis. *Solid State Ionics*, *368*, 115692.

Ammonia

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



Intensified Ammonia Solar Reactor for Green Ammonia Manufacture and Gen3 Thermochemical Energy Storage

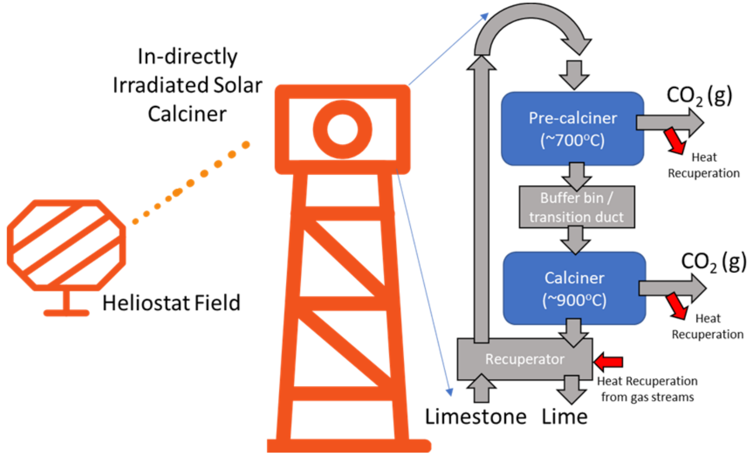
PI: Mahdi Malmali

TEXAS TECH UNIVERSITY

UNIVERSITY OF MINNESOTA

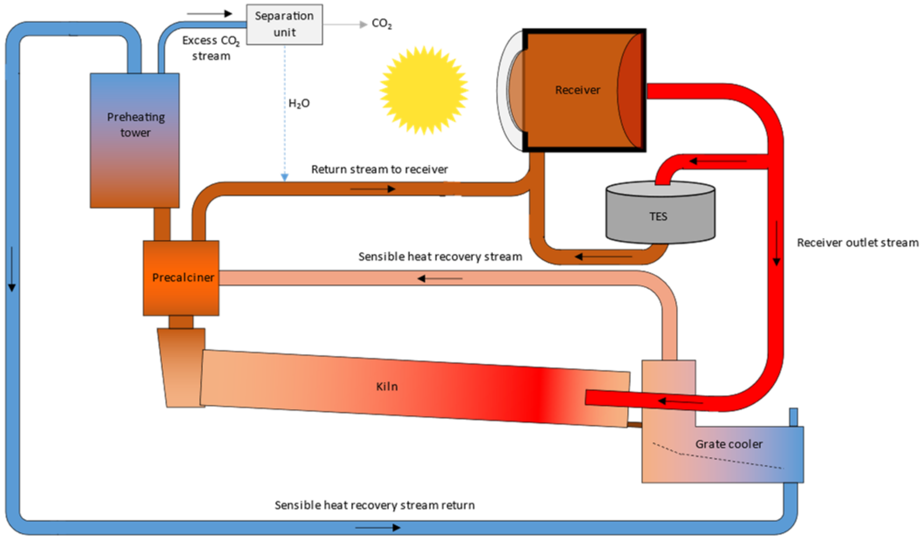
RTI INTERNATIONAL

Solar Cement



Development of an In-directly Irradiated Solar Thermal Calcination System, nominally at 400kW$_{th}$, for On-Sun Testing.

Heliogen, Colorado School of Mines, University of Michigan, CTP Ceramic Tubular Products, LLC, Martin Marietta

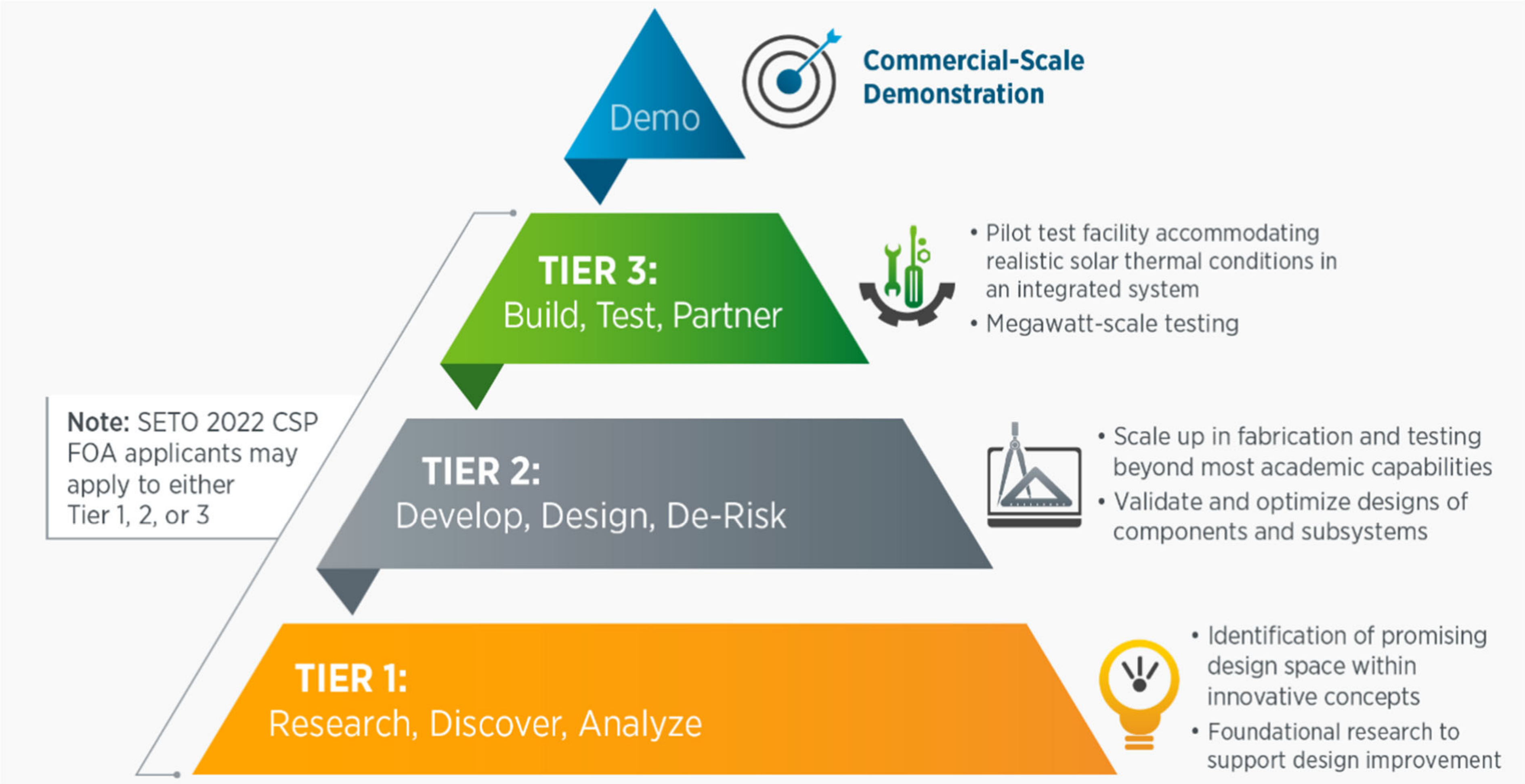


Solar-Thermal Mixed-Media Enhancement and Decarbonization of Clinker Formation (Solar MEAD)

PI: Nathan Schroeder

Sandia National Laboratories, Synhelion, CEMEX

Scaling Technology Development



ORISE Science & Technology Policy Fellowship

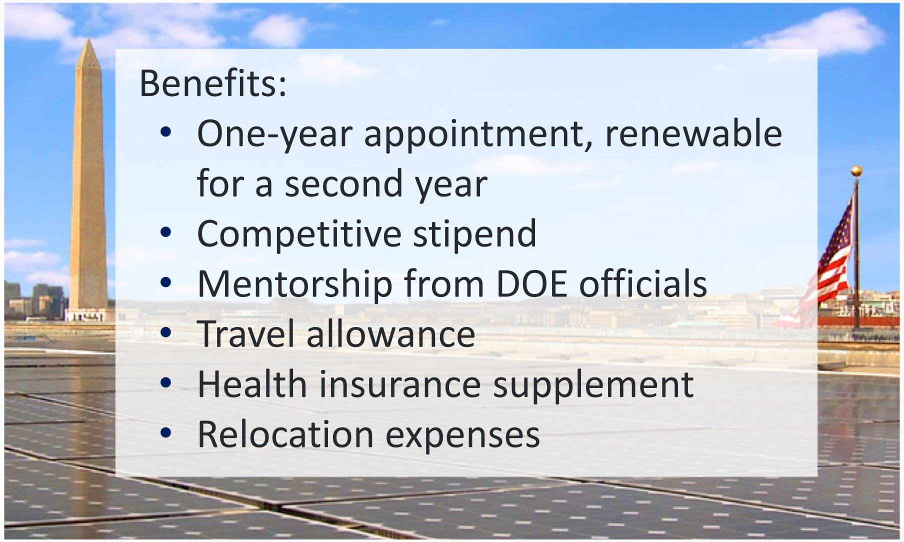
Develop leadership skills in science and technology policy by designing and implementing national research and development (R&D) programs

Strategic Areas:

- Photovoltaic technologies
- Concentrating solar-thermal power technologies
- Grid systems integration technologies
- Behavioral science, strategic analysis, and technical assistance
- Manufacturing and technology transfer
- Environmental justice and stakeholder engagement
- Communications and outreach

Eligibility:

Open to physical, natural, and social scientists, engineers, and entrepreneurs with bachelor's, master's, or doctoral degrees, and established professionals with post-degree experience. Must be a U.S. citizen or have Permanent Resident (Green Card) status.



Benefits:

- One-year appointment, renewable for a second year
- Competitive stipend
- Mentorship from DOE officials
- Travel allowance
- Health insurance supplement
- Relocation expenses

Applications are accepted on a rolling basis with two annual review dates: **January 15 | June 15**

VISIT: bit.ly/SETO-Fellowships • **EMAIL:** DOE-RPP@orau.org

QUESTIONS?

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