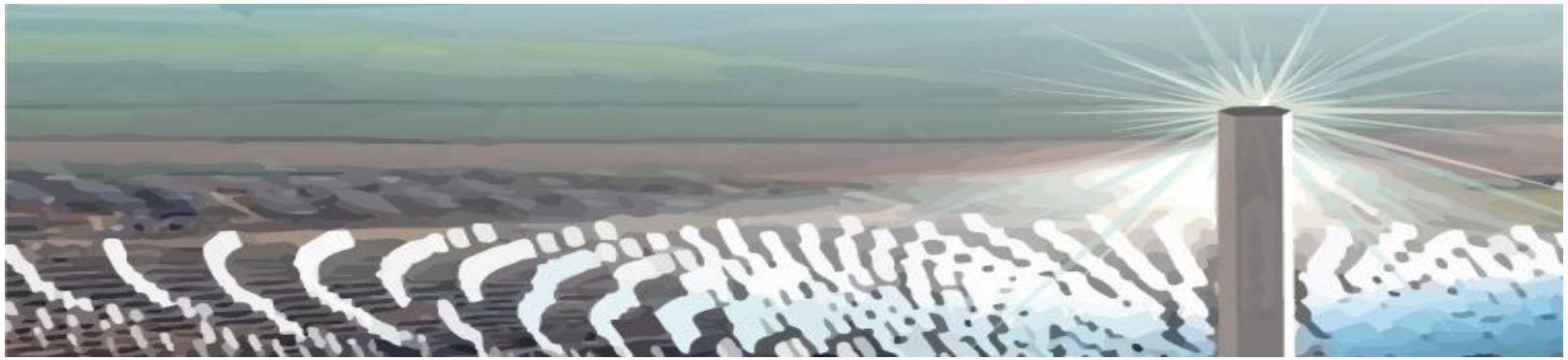
SunShot
U.S. Department of Energy



# DOE Workshop on Gen 3 CSP Technology

energy.gov/sunshot

February 1-2, 2017

Dr. Avi Shultz, Acting CSP Program Manager

# Day One Agenda, Wednesday February 1, 2017

- 12:45 – 1:00 Welcome and introductions
- 1:00 – 2:15 CSP and Gen 3 overview, meeting objectives – **Avi Shultz, DOE**

  Technology Development Roadmap Overview –Research, Components and System integration – **Mark Lausten, DOE**
- 2:15 – 2:45 Gen 3 System Analysis – **Craig Turchi, NREL**
- 2:45 – 3:00 Self Introductions of the researchers and component manufactures
- 3:00 – 3:15 Break
- 3:15 – 4:00 Molten Salt Technology – overview and research needs – **Judith Vidal, NREL**
- 4:00 - 4:45 Solid Media Technology – overview and research needs – **Cliff Ho, Sandia**
- 4:45 - 5:30 Gas-Phase Technology – overview and research needs – **Mike Wagner, NREL**
- 5:30 – 6:00 Open discussion and wrap-up – **Mark Lausten, DOE**
- 6:30 – 9:00 Networking reception and dinner – **Fahrenheit 250 BBQ, 7042 Folsom Blvd, Sacramento, CA**

- **Wi-Fi Network: SacLinkSecure**
- **login:** alum-guest **password:** ACguest92013

# Gen 3 Workshop Objectives

- Overview of next gen CSP systems to achieve low-cost targets of SunShot with $sCO_2$ cycles identified in **Gen3 Roadmap**
- Highlight technologies capable of temperatures beyond materials used in today's plants
- Identify research, industry and system integrator opportunities and tech development needs
- Facilitate communication and networking among the research and development CSP community in preparation for upcoming DOE Funding Opportunities


**Concentrating Solar Power Gen3 Demonstration Roadmap**

Mark Mehos, Craig Turchi, Judith Vidal, Michael Wagner, and Zhiwen Ma
*National Renewable Energy Laboratory*
*Golden, Colorado*

Clifford Ho, William Kolb, and Charles Andraka
*Sandia National Laboratories*
*Albuquerque, New Mexico*

Alan Kruizenga
*Sandia National Laboratories*
*Livermore, California*

**NREL is a national laboratory of the U.S. Department of Energy**
**Office of Energy Efficiency & Renewable Energy**
**Operated by the Alliance for Sustainable Energy, LLC**

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

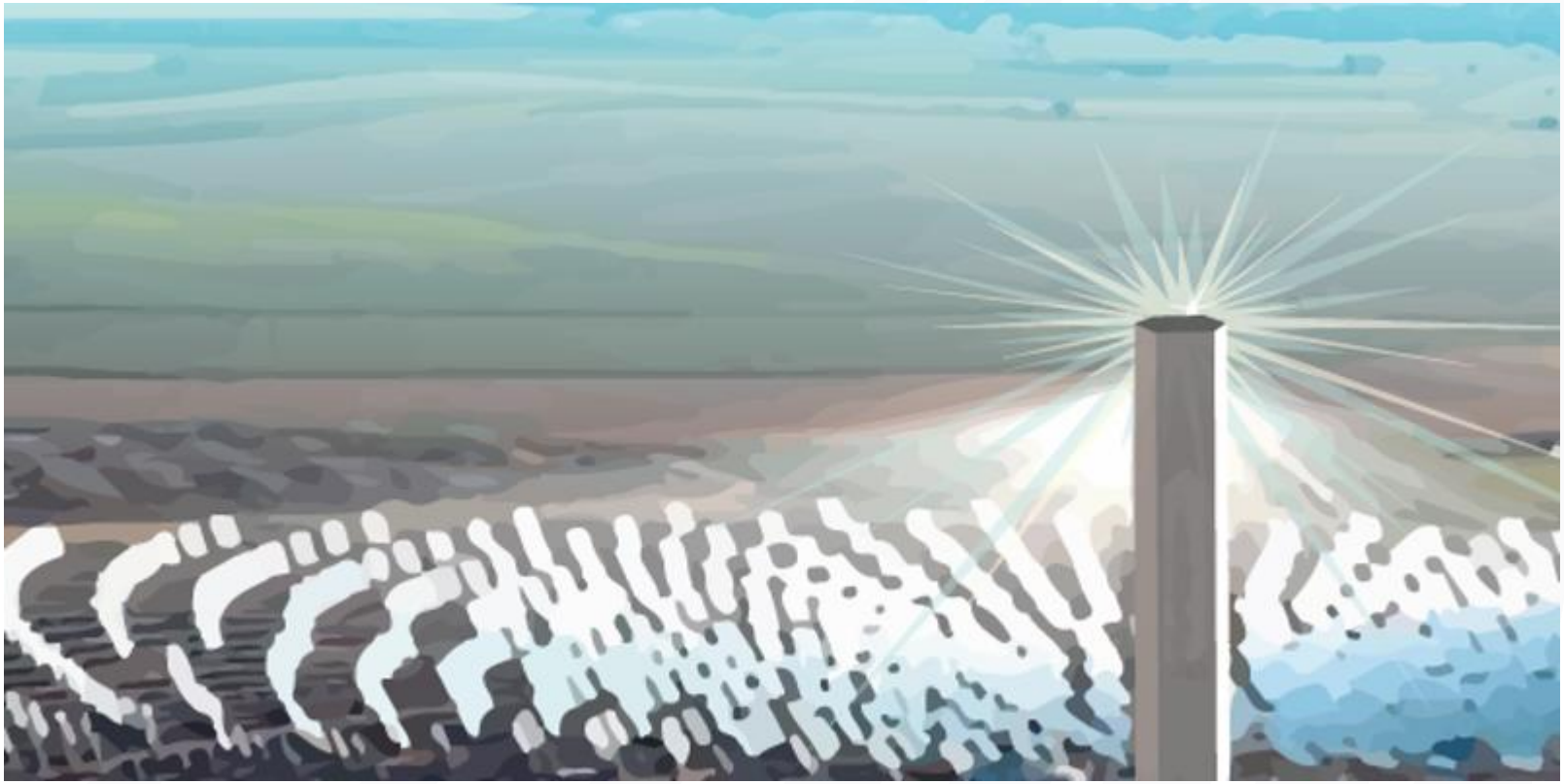
**Technical Report**
NREL/TP-5500-67464
January 2017

Contract No. DE-AC36-08GO28308

# Gen 3 Workshop Objectives

- **The goal of DOE's Gen 3 effort is to develop integrated systems capable of delivering high temperature thermal energy to advanced power cycles**
- Stakeholder groups with an interest in Gen 3 CSP:
  - Utilities, Regulators, Analysts
  - Investors
  - System Integrators/Developers
  - Researchers
  - Component Manufacturers

# SunShot CSP and Gen 3 Overview



# CSP in the US

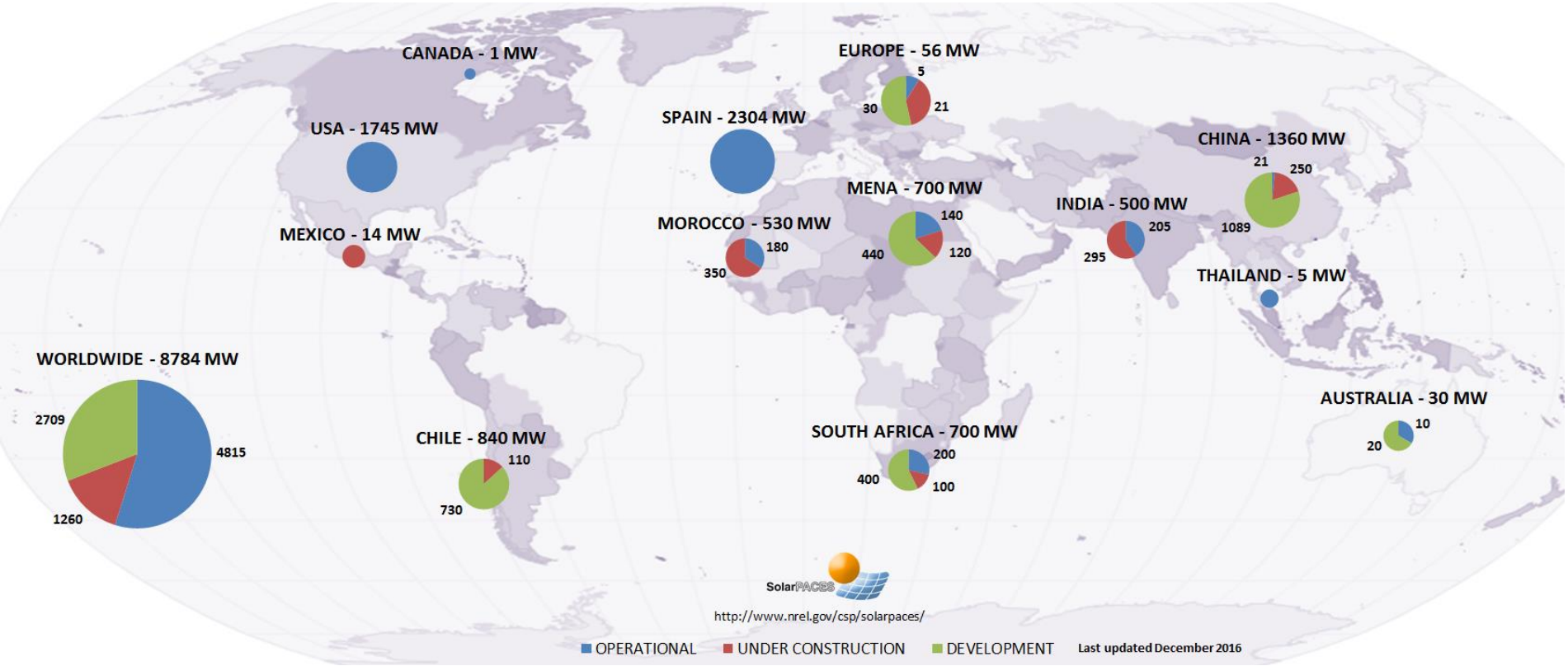




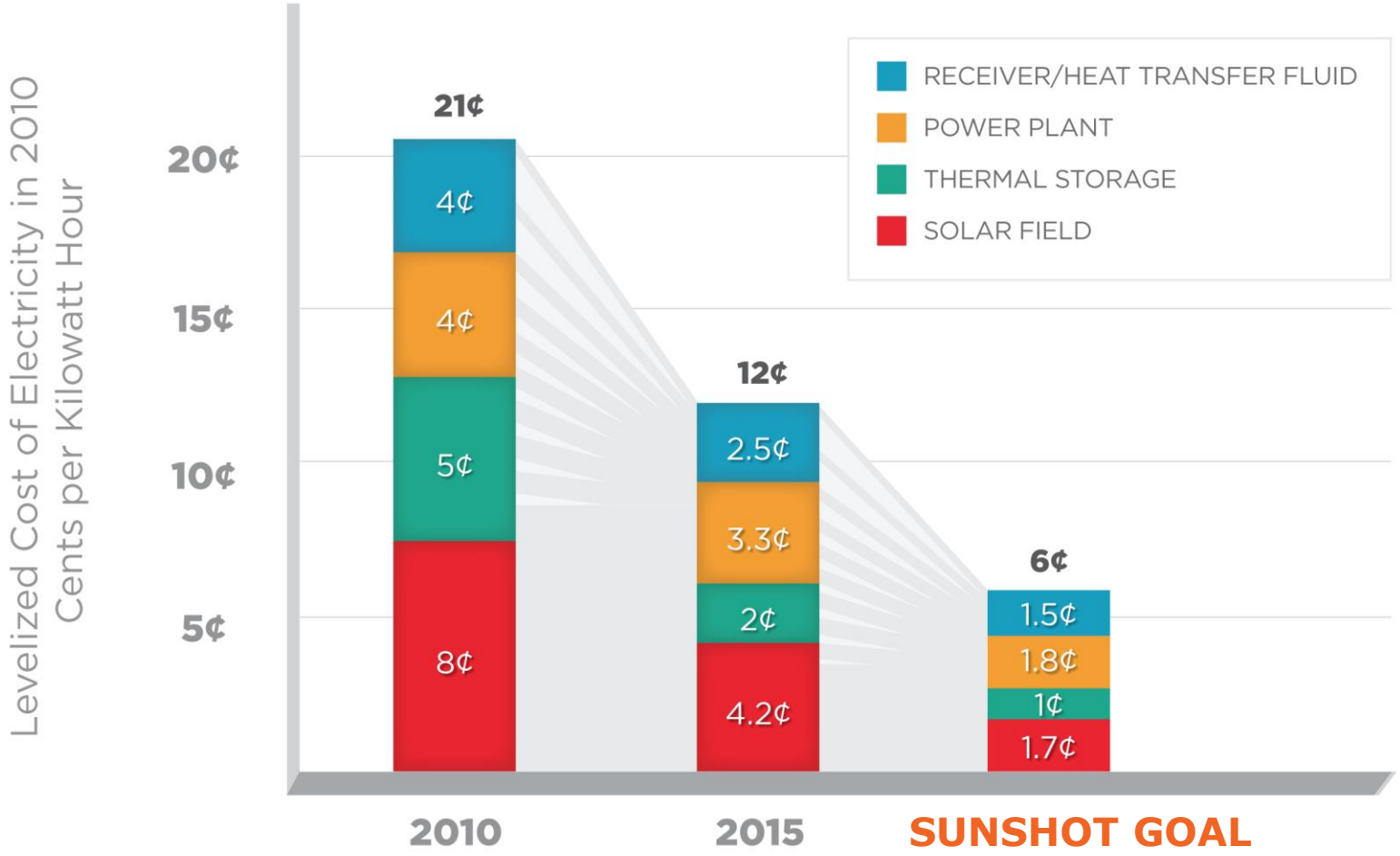
| Project | Solana | Ivanpah | Genesis | Crescent Dunes | Mojave |
|---|---|---|---|---|---|
| Utility | APS | SCE + PG&E | PG&E | NVE | PG&E |
| State | Arizona | California | California | Nevada | California |
| Size | 280 MW | 392 MW | 250 MW | 110 MW | 280 MW |
| Technology | Trough/Storage | Tower | Trough | Tower/Storage | Trough |
| COD | October 2013 | February 2014 | March 2014 | February 2016 | January 2015 |
| DOE Loan | $1.45 B | $1.63 B | $0.85 B | $.74 B | $1.2 B |
| Company | Abengoa | BrightSource | NextEra | SolarReserve | Abengoa |

Total New CSP in US: 1,312 MW

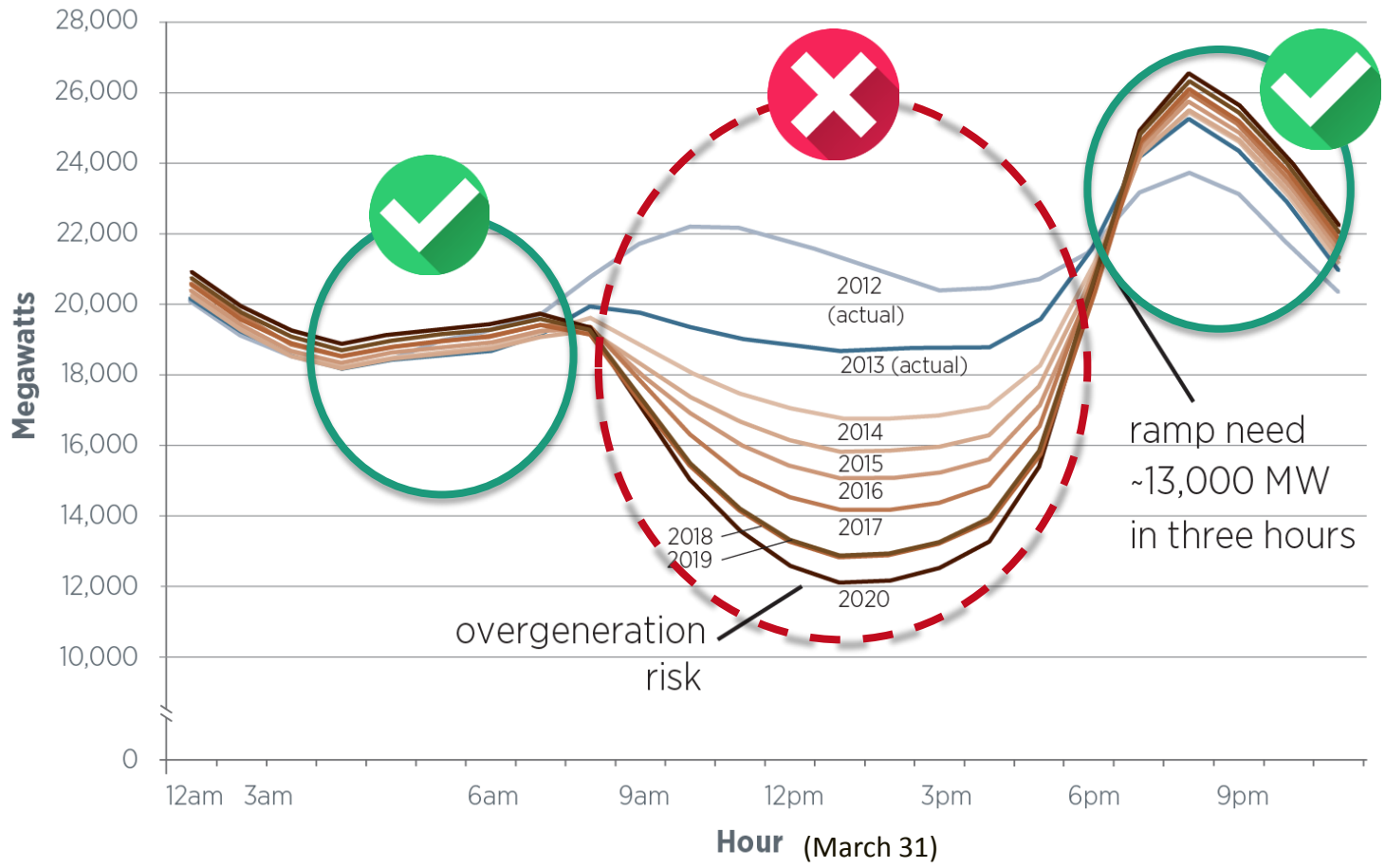
# CSP Globally



# The Falling Costs of CSP



# Near Terms Opportunities for CSP: Flexible, Renewable, Dispatchable Energy

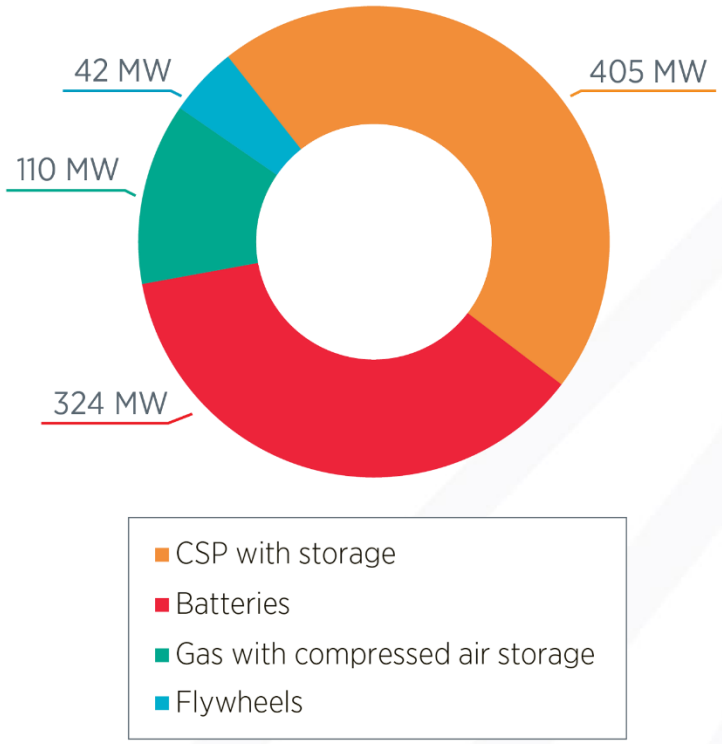



*CSP can readily be configured to meet uncertain demands of the future grid by varying the relative sizes of the solar field, storage, and power block*

http://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

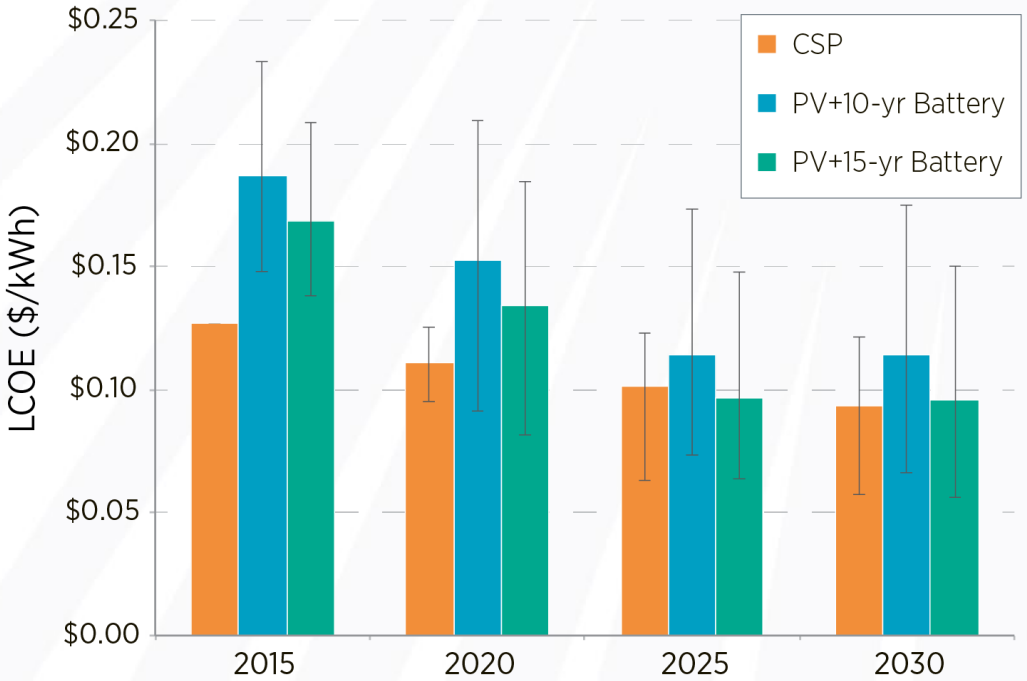
# U.S. Deployment of Storage Technologies

U.S. Generating Capacity, Storage (MW)
Non-hydro, as of June 2016




*Source: EIA*

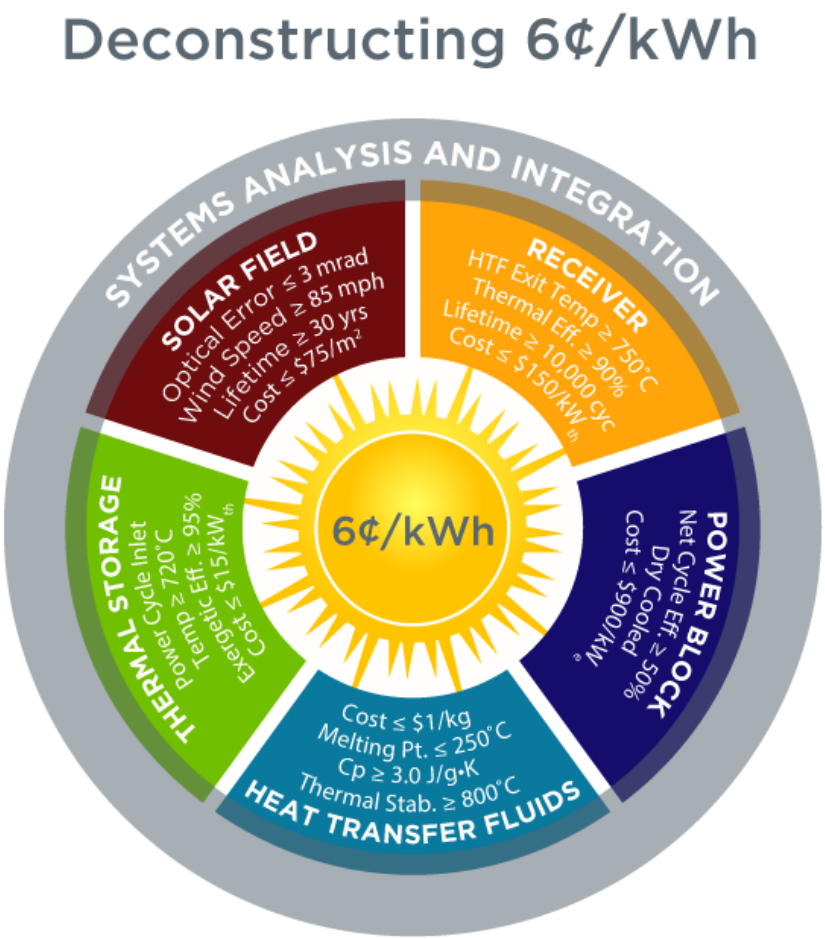
LCOE Comparison: CSP vs PV
(six hours of storage), 2015-2030

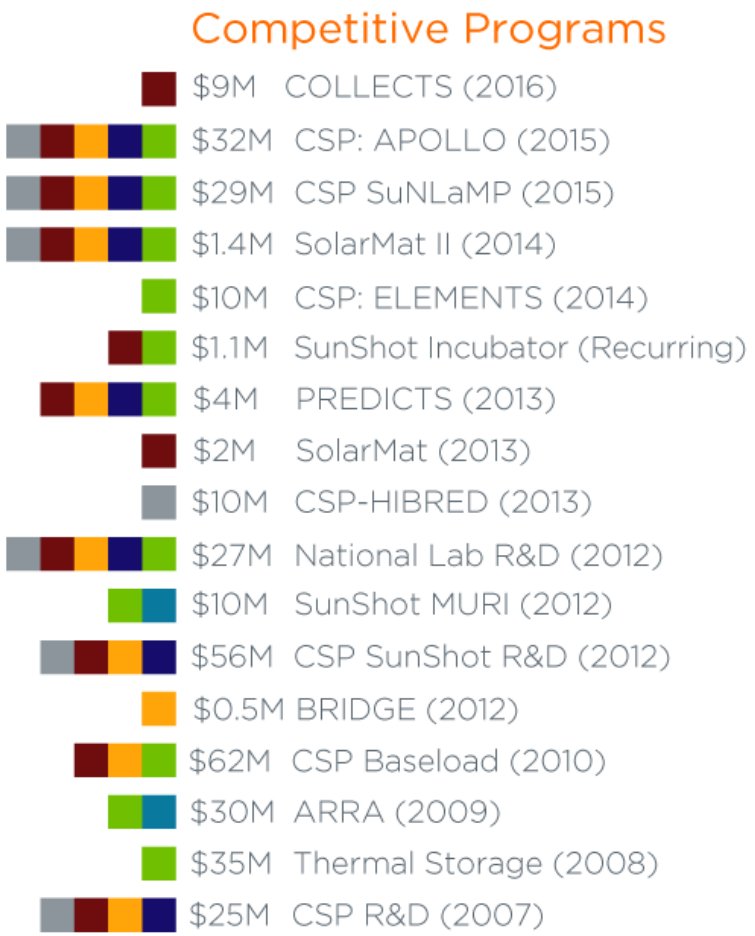



Mid case is shown with uncertainty bars representing the span of the low to high cases.

*Feldman, Margolis, Denholm, Stekli, 2016*

# CSP Competitive Initiatives

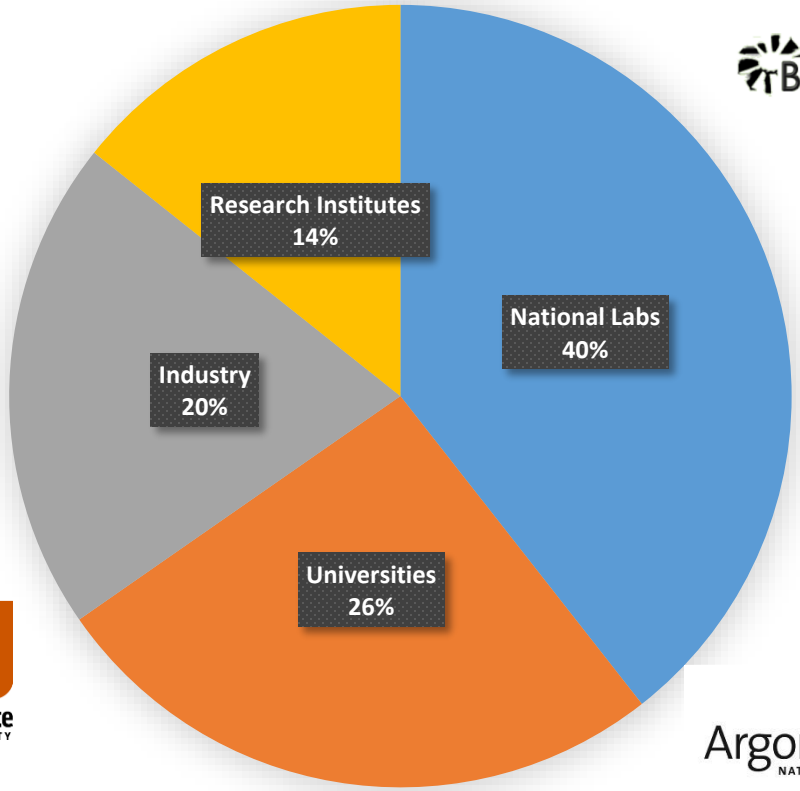



- *DOE CSP Program budget of $40-50M per year*
- *Gen 3 is the Program's primary 2017 initiative*

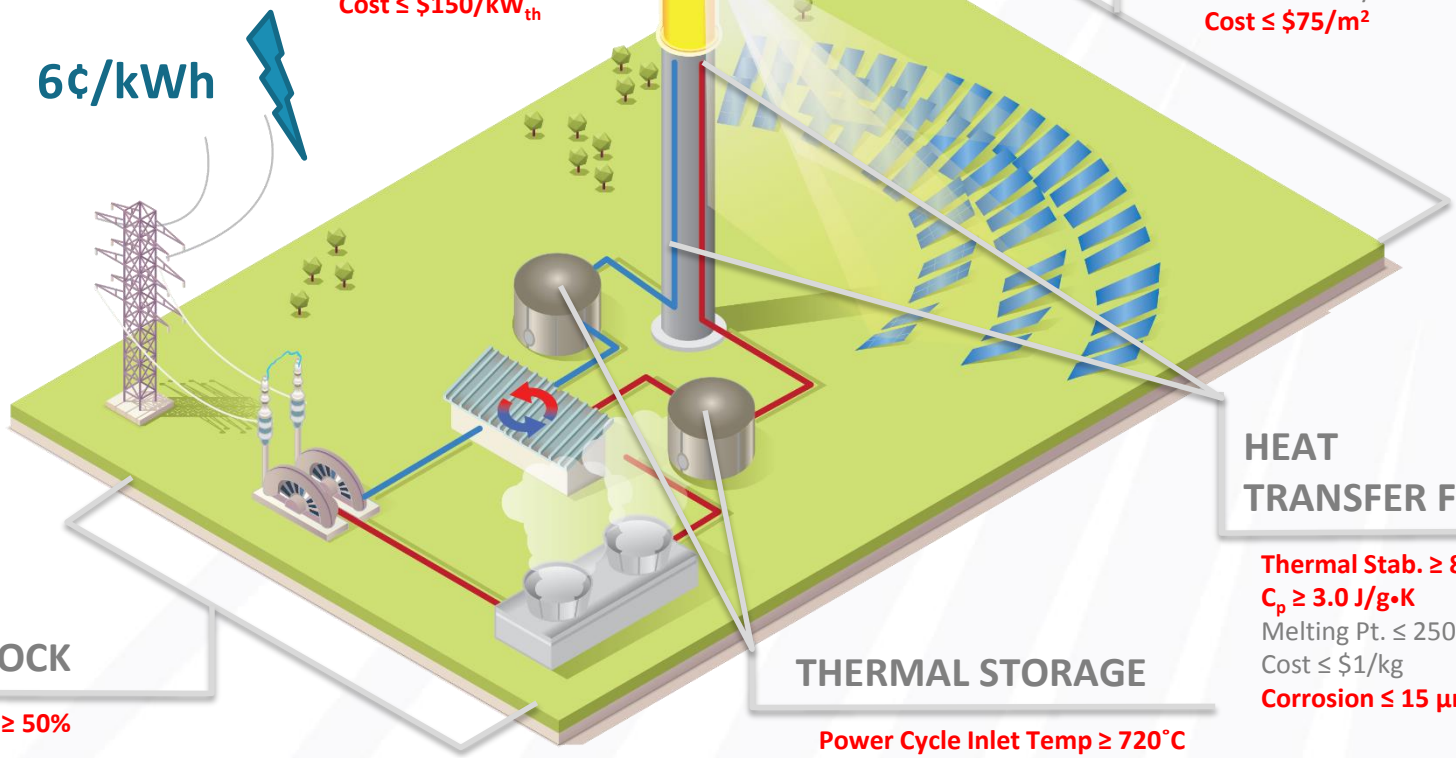
# CSP Program Funding

## Funding by Awardee Type




*As an applied program, 20% cost-share is typically required for R&D*

# CSP Program Technical Targets




## RECEIVER

**HTF Exit Temp ≥ 720˚C**
Thermal Eff. ≥ 90%
Lifetime ≥ 10,000 cyc
**Cost ≤ $150/kW$_{th}$**

## SOLAR FIELD

Optical Error ≤ 3 mrad
Wind Speed ≥ 85 mph
Lifetime ≥ 30 yrs
**Cost ≤ $75/m²**

## HEAT TRANSFER FLUID

**Thermal Stab. ≥ 800˚C**
**$C_p$ ≥ 3.0 J/g•K**
Melting Pt. ≤ 250˚C
Cost ≤ $1/kg
**Corrosion ≤ 15 µm/yr**

## THERMAL STORAGE

**Power Cycle Inlet Temp ≥ 720˚C**
Energy Eff. ≥ 99%
Exergy Eff. ≥ 95%
**Cost ≤ $15/kWh$_{th}$**

## POWER BLOCK

**Net Cycle Eff. ≥ 50%**
Dry Cooled
**Cost ≤ $900/kW$_e$**

*Low-cost CSP is enabled by exceeding temperature limits of current molten nitrate salts*

# Third Generation CSP: 700 °C+
# Leveraging Cross-Cutting STEP Initiative

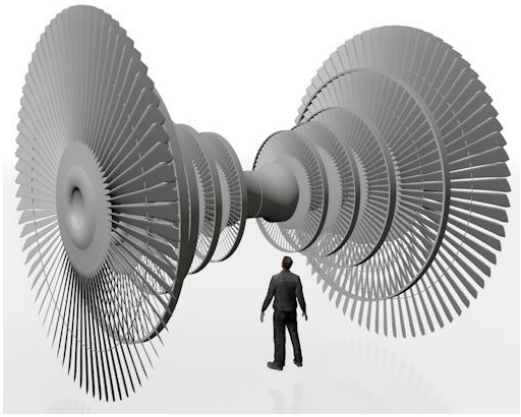
*Supercritical CO2 Power Cycles*

- Smaller Footprint
- Higher Efficiency
- Reduced Water Use
- Scalability

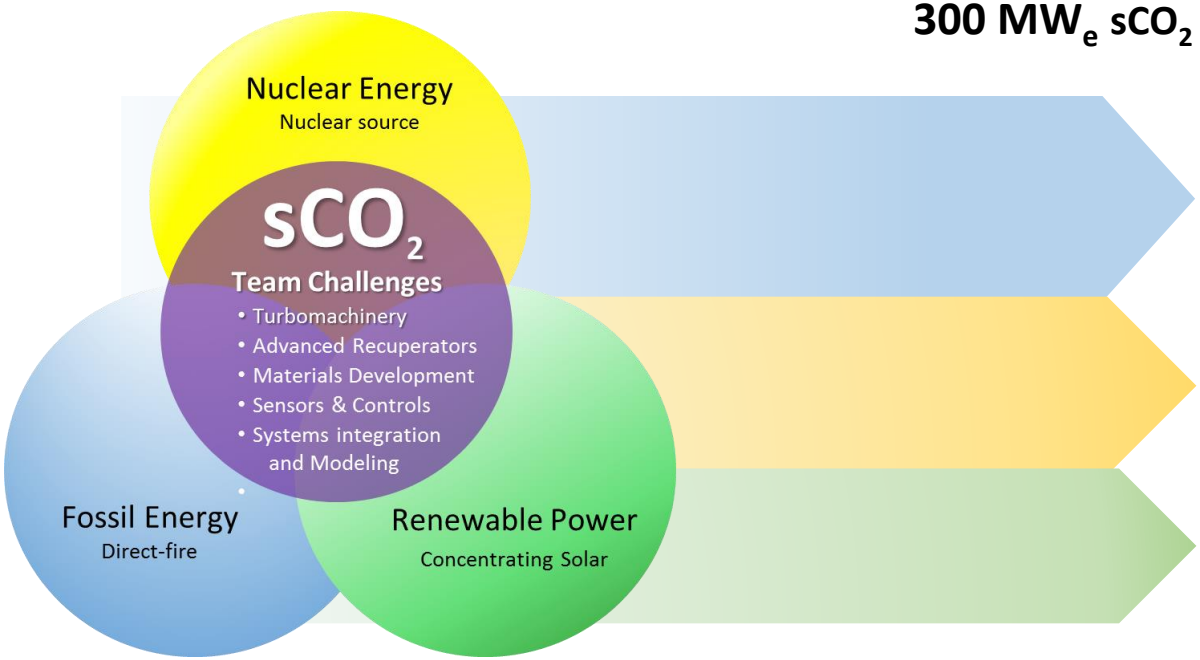
*National benefits*:

- Enhance U.S. energy independence and energy security
- Boost U.S. leadership in energy technology
- Lower cost of electricity generation
- Create jobs

**300 $MW_e$ $sCO_2$**



**300 $MW_e$ Steam Turbine**




## Crosscut Team Goals

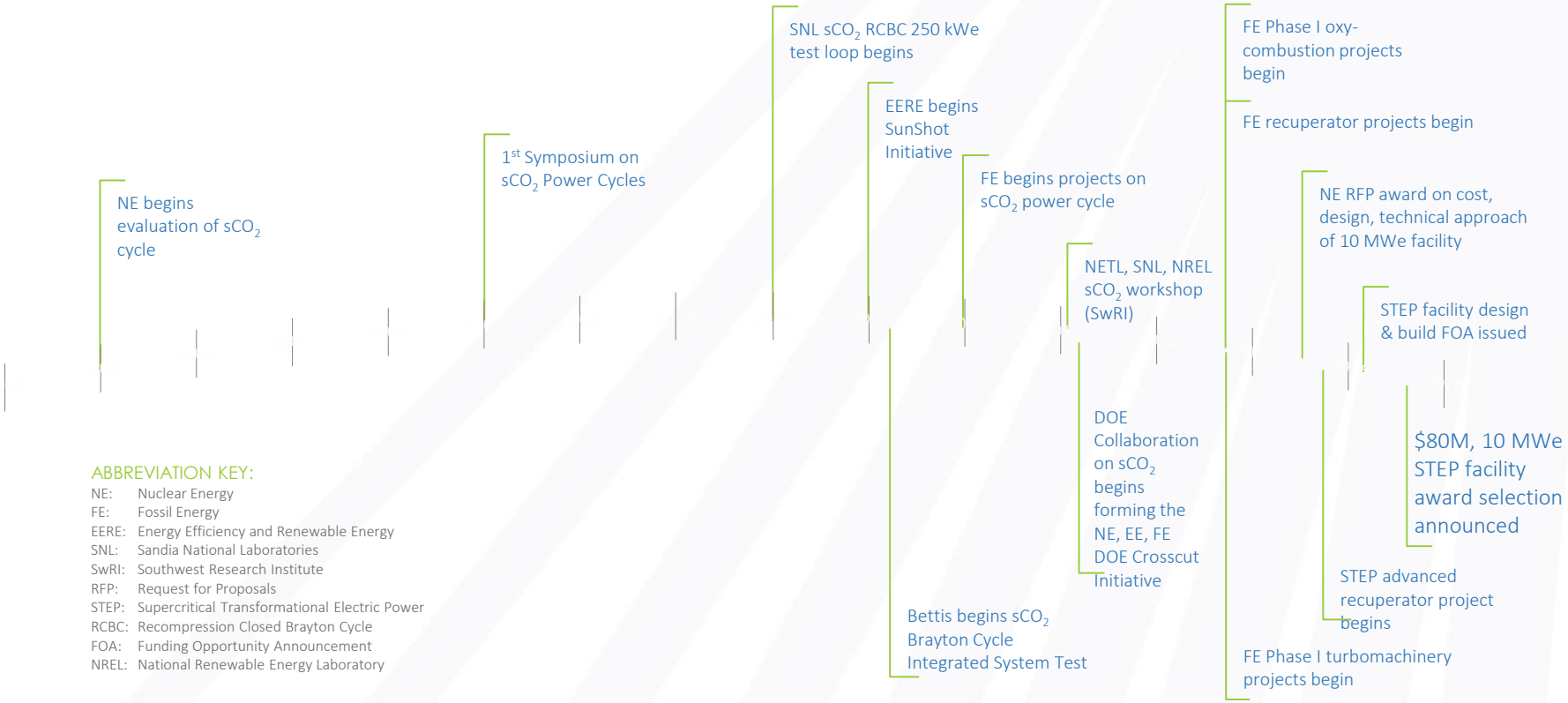
- Coordinate technology scale up and integration
- Launch facilities to test and validate the technology

**2020 Operation**
Indirect-fired 10 MWe pilot facility

**2026 Operation**
Commercial-scale demonstration plant

- Demonstrate thermal cycle efficiency of ≥ 50%
- Optimize performance and lower capital costs

# $sCO_2$ Power Cycles – DOE Development History




ABBREVIATION KEY:

| | |
|---|---|
| NE: | Nuclear Energy |
| FE: | Fossil Energy |
| EERE: | Energy Efficiency and Renewable Energy |
| SNL: | Sandia National Laboratories |
| SwRI: | Southwest Research Institute |
| RFP: | Request for Proposals |
| STEP: | Supercritical Transformational Electric Power |
| RCBC: | Recompression Closed Brayton Cycle |
| FOA: | Funding Opportunity Announcement |
| NREL: | National Renewable Energy Laboratory |

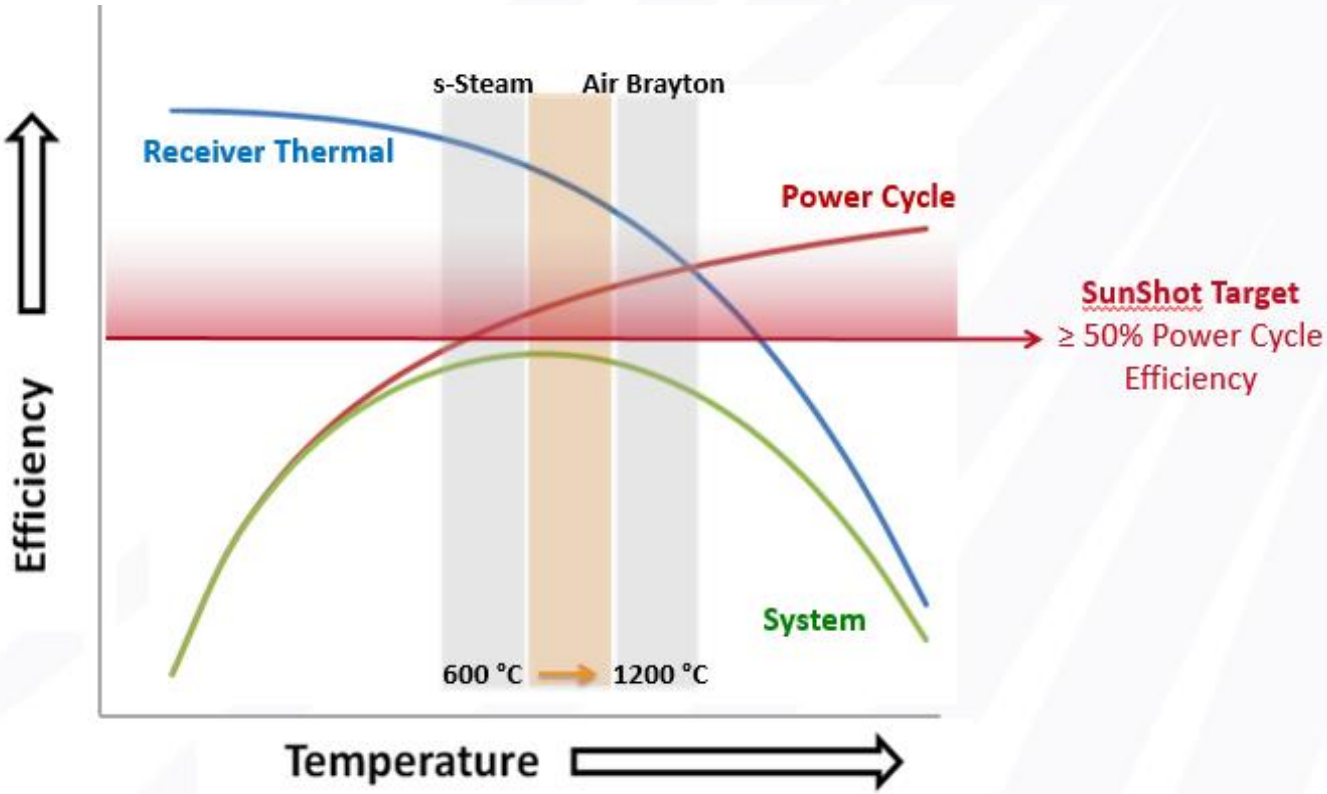
# Third Generation CSP: 700 °C+

## Science Principles

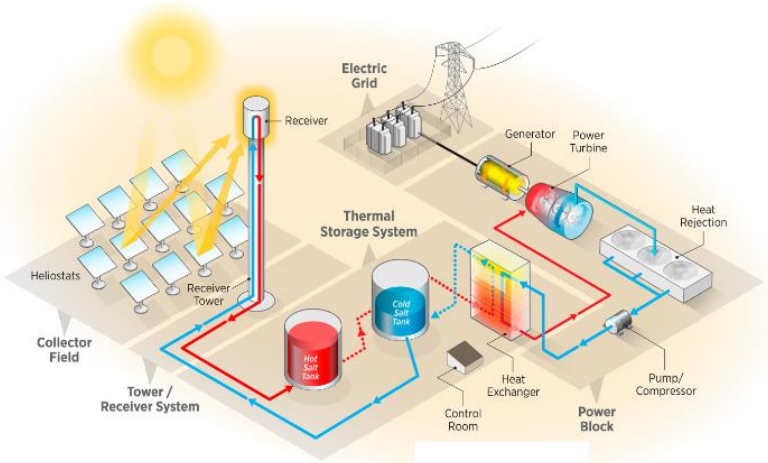
- Carnot vs. radiation optimum: 650 – 750°C
- Power Cycle Isothermal heat input higher $\eta$
- CSP most suitable for Power Blocks <150 MW
- Increased efficiency critical to lower CSP costs

## $sCO_2$ Power Cycles

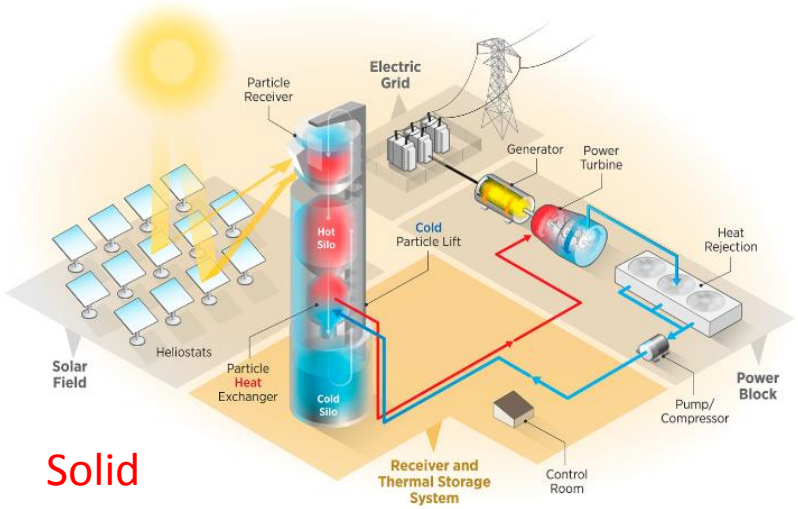
- Can achieve $\eta$ > 50% operating at >700°C
- Scale from 50-500 MW and can scale to 10 MW with modest $\eta$ decrease
- Suitable for dry cooling



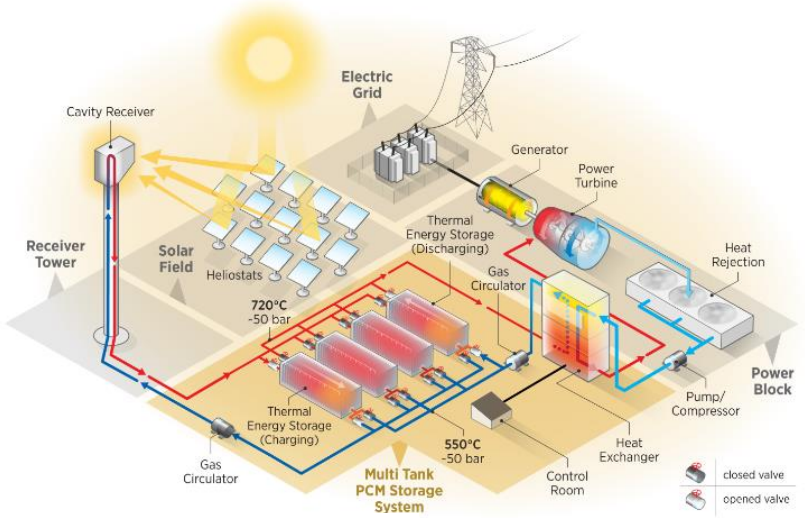
# Gen3 CSP – High Temp. Solar Heat Transfer Systems




Liquid




Solid




Gas

*To achieve cost reductions through high efficiency $sCO_2$ cycles, systems to deliver solar heat > 700 °C must be developed*

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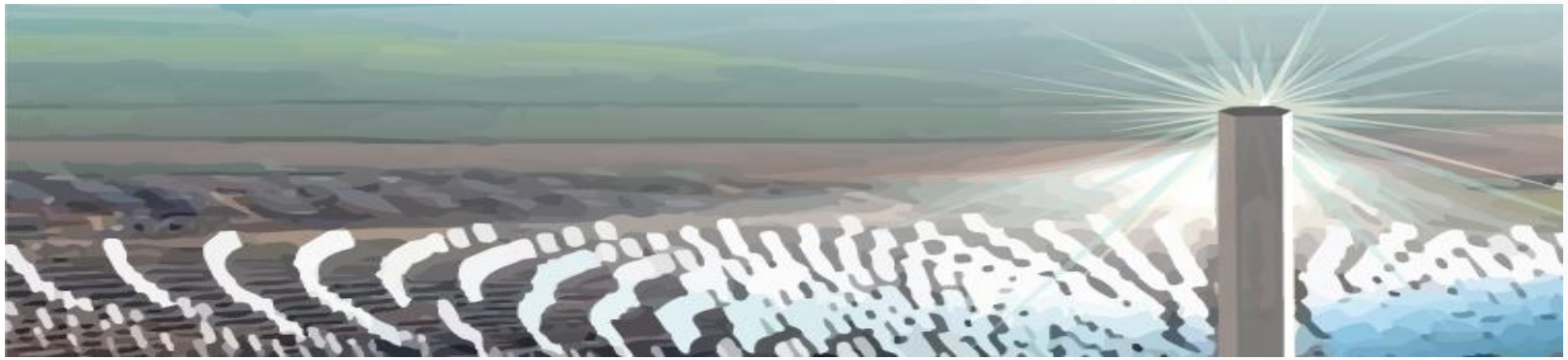

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SunShot Initiative, Solar Energy Technologies Office