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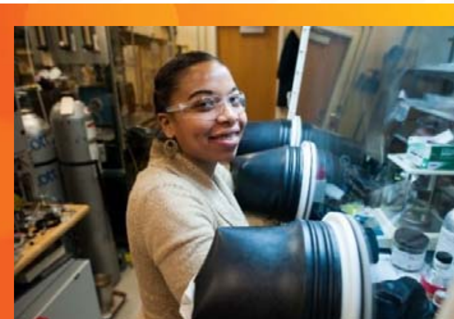


Concentrating Solar Thermal Power Program Overview

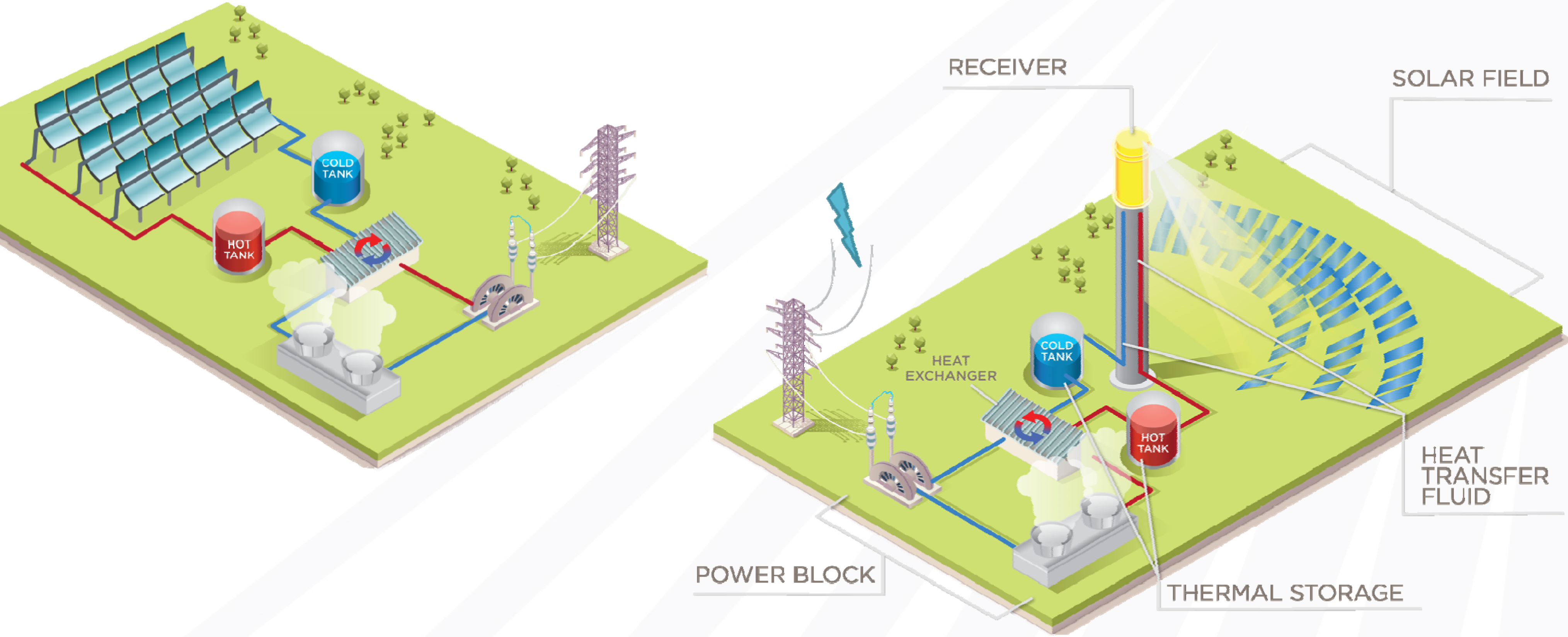
Dr. Avi Shultz, CSP Program Manager

Supercritical CO_2 Power Cycles Symposium

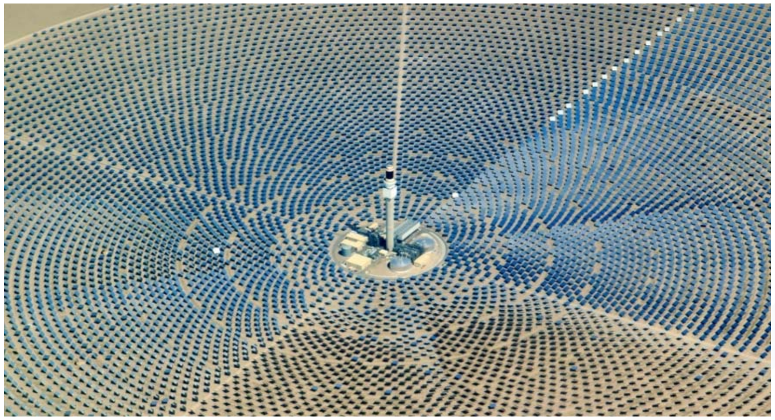
March 28, 2018

energy.gov/solar-office

CSP with Storage is Solar Energy On-Demand



CSP is Deployed Worldwide



4.8 GW CSP deployed globally

1.8 GW CSP deployed in the U.S.

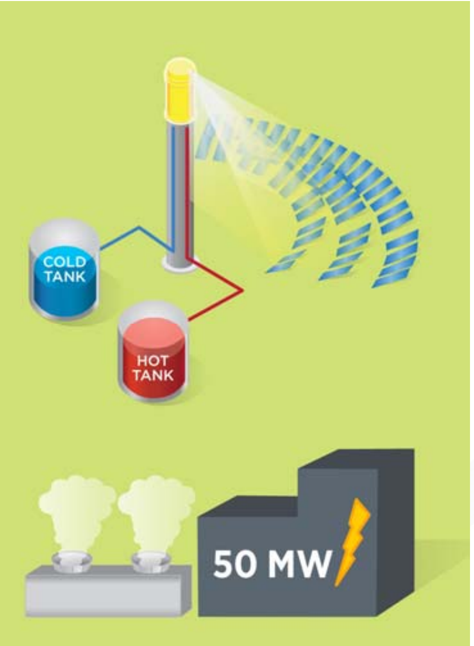
0.4 GW CSP deployed in the U.S. *with storage*

Since 2016 CSP's share of electricity generation:

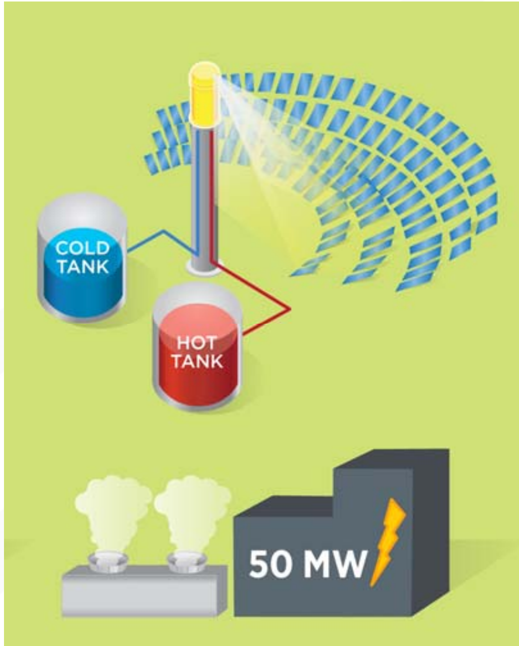
- 1% of California
- 2% of Spain

CSP: Flexible Designs for an Evolving Grid

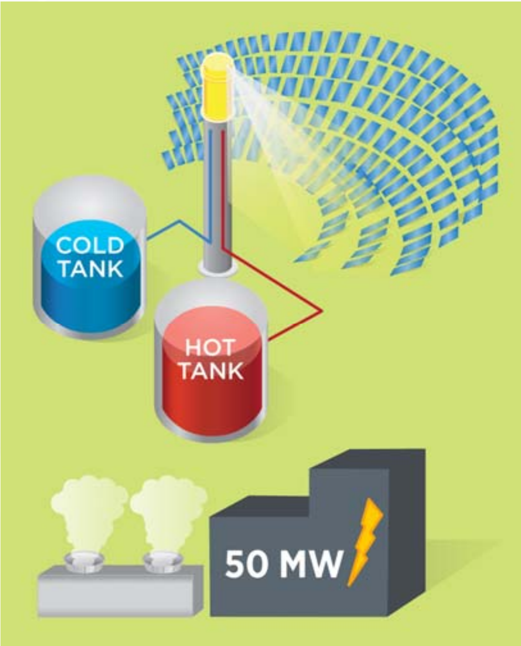
'Peaker'
(≤6 hours of storage)



'Intermediate'
(9 hours of storage)

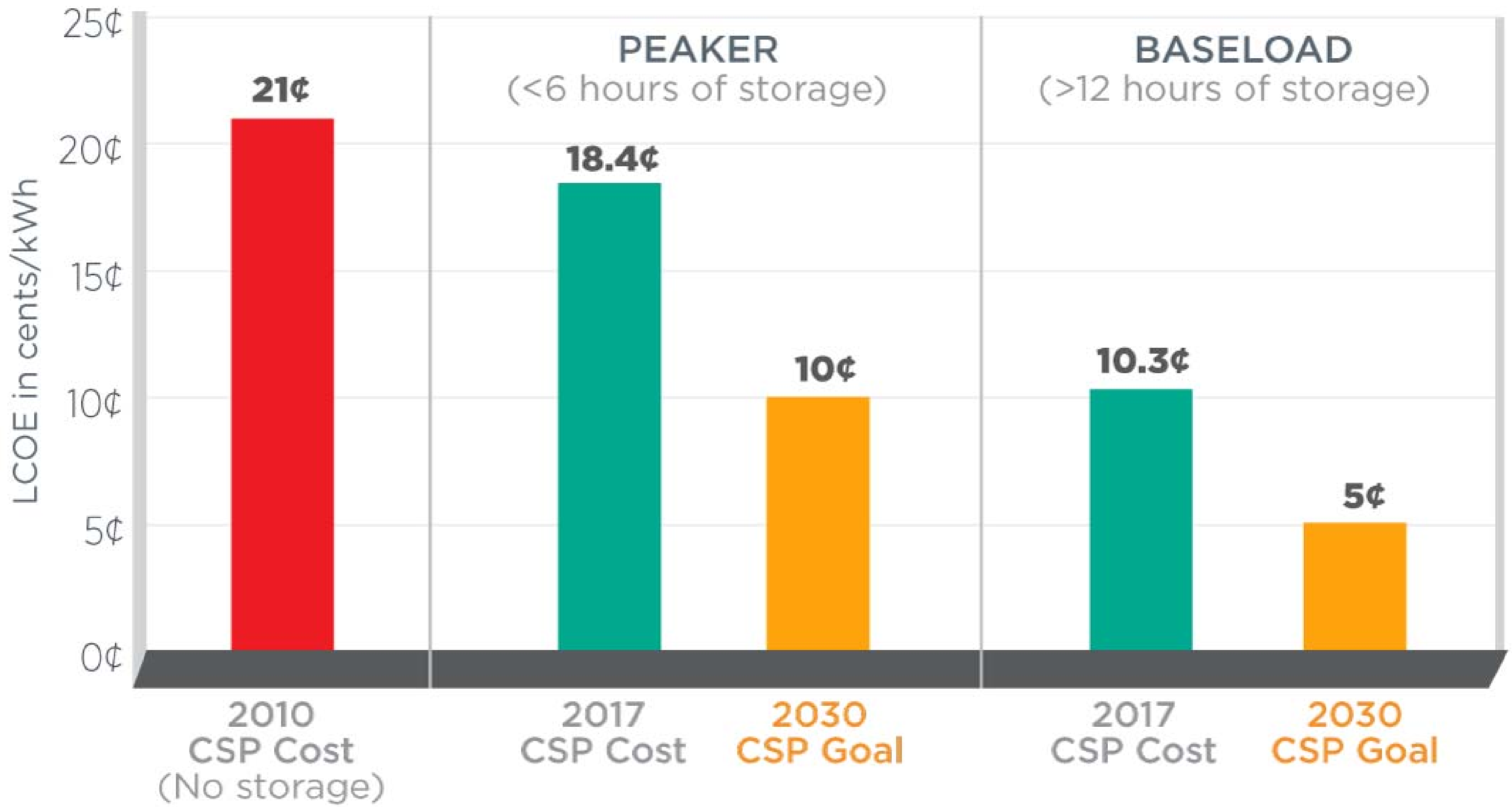


'Baseload'
(≥12 hours of storage)

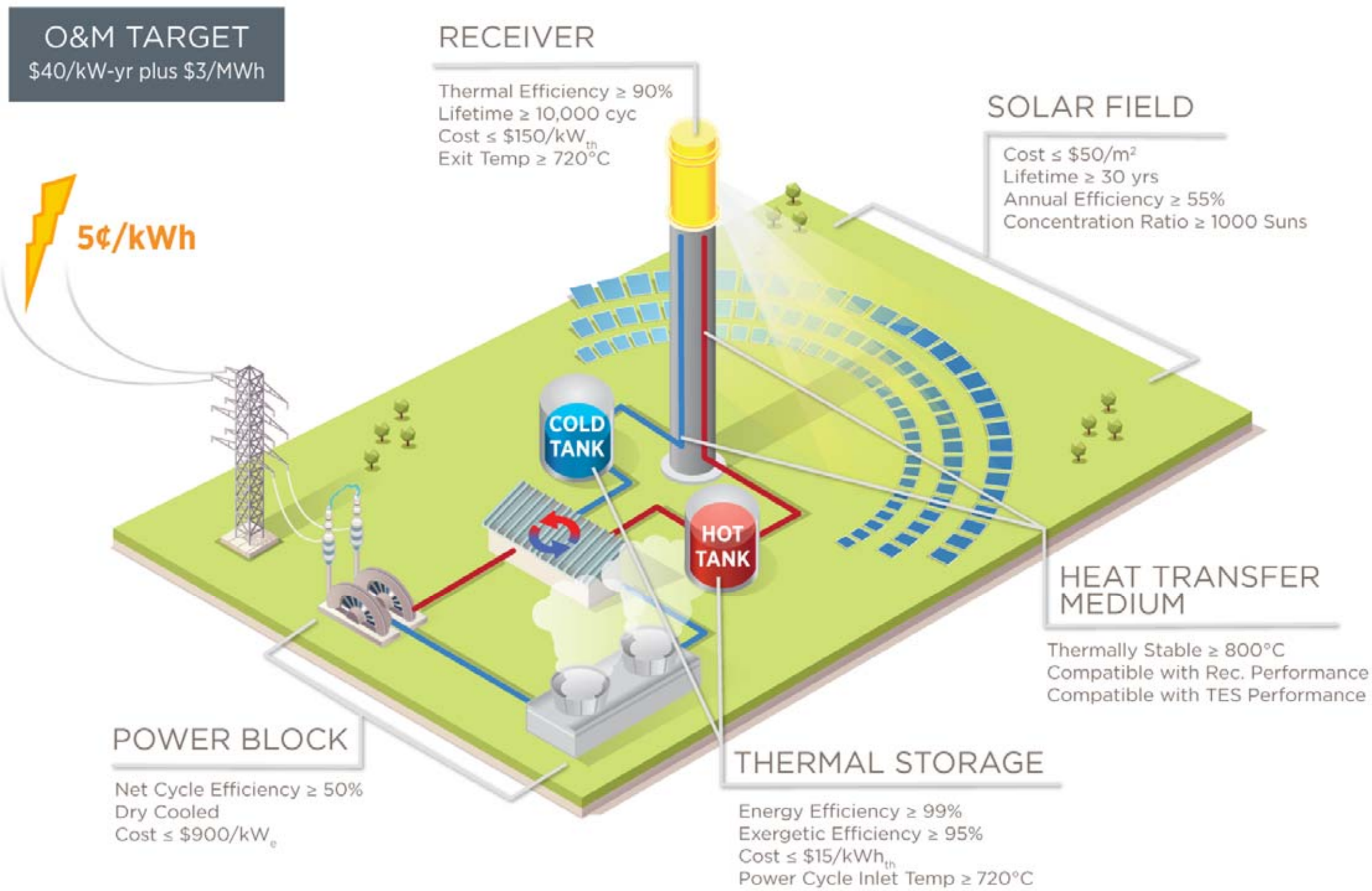


By choosing the size of the solar field and thermal energy storage, the same CSP technology can be configured to meet evolving demands of the future grid

2030 Levelized Cost of Electricity Targets



CSP Program Technical Targets



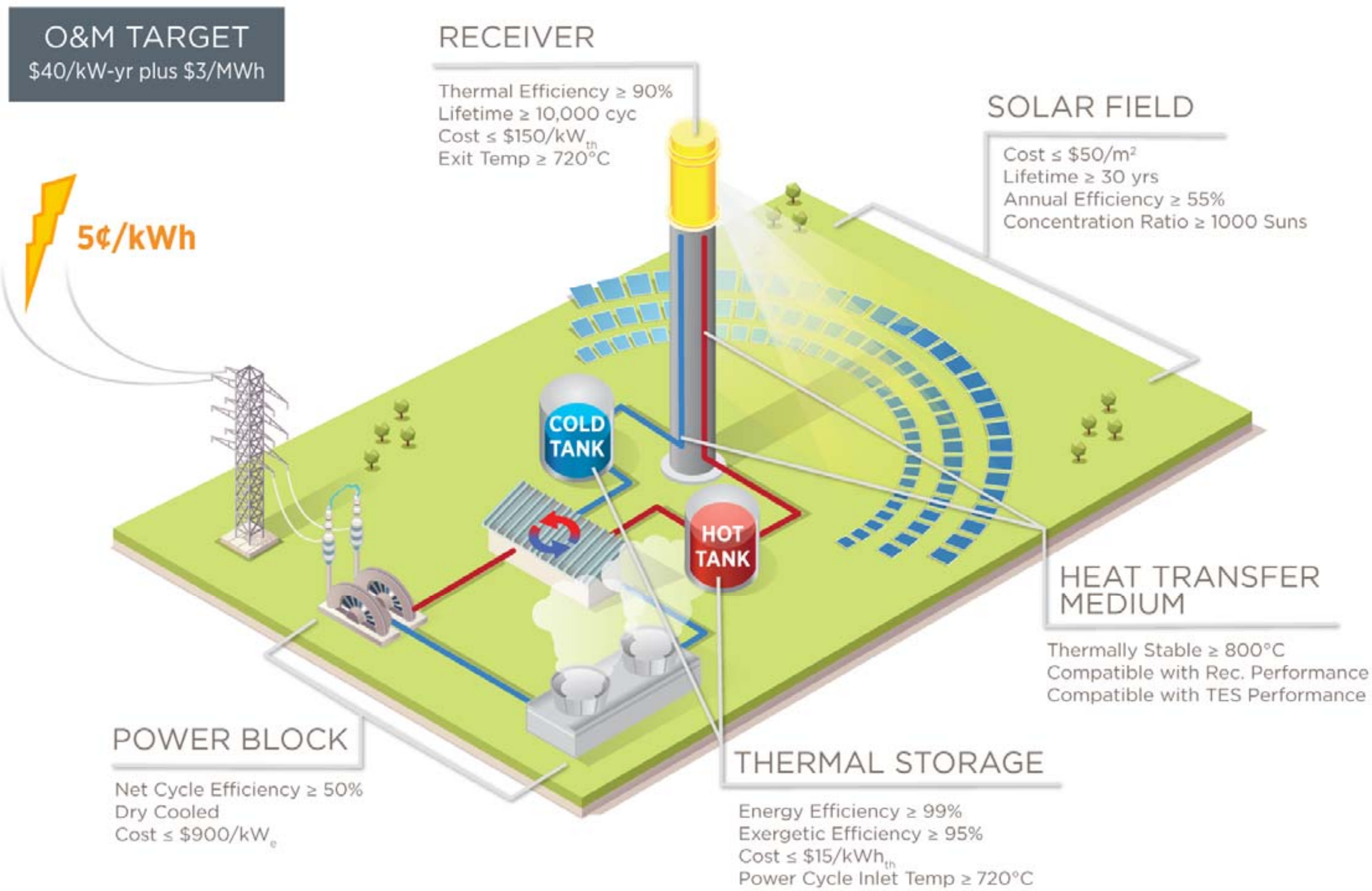
Collector Field
- Optical Physics
- Structural design and dynamics
- Manufacturing and automation
- Sensors and control

Receivers
- Optical properties
- Coatings
- High temperature materials
- Chemistry
- Heat Transfer, Fluid Mechanics

TES and HTF
- Chemistry
- High temperature materials
- Materials Science
- Heat Transfer, Fluid Mechanics

Power Block
- High temperature materials
- Turbomachinery
- Manufacturing and automation
- Sensors and control

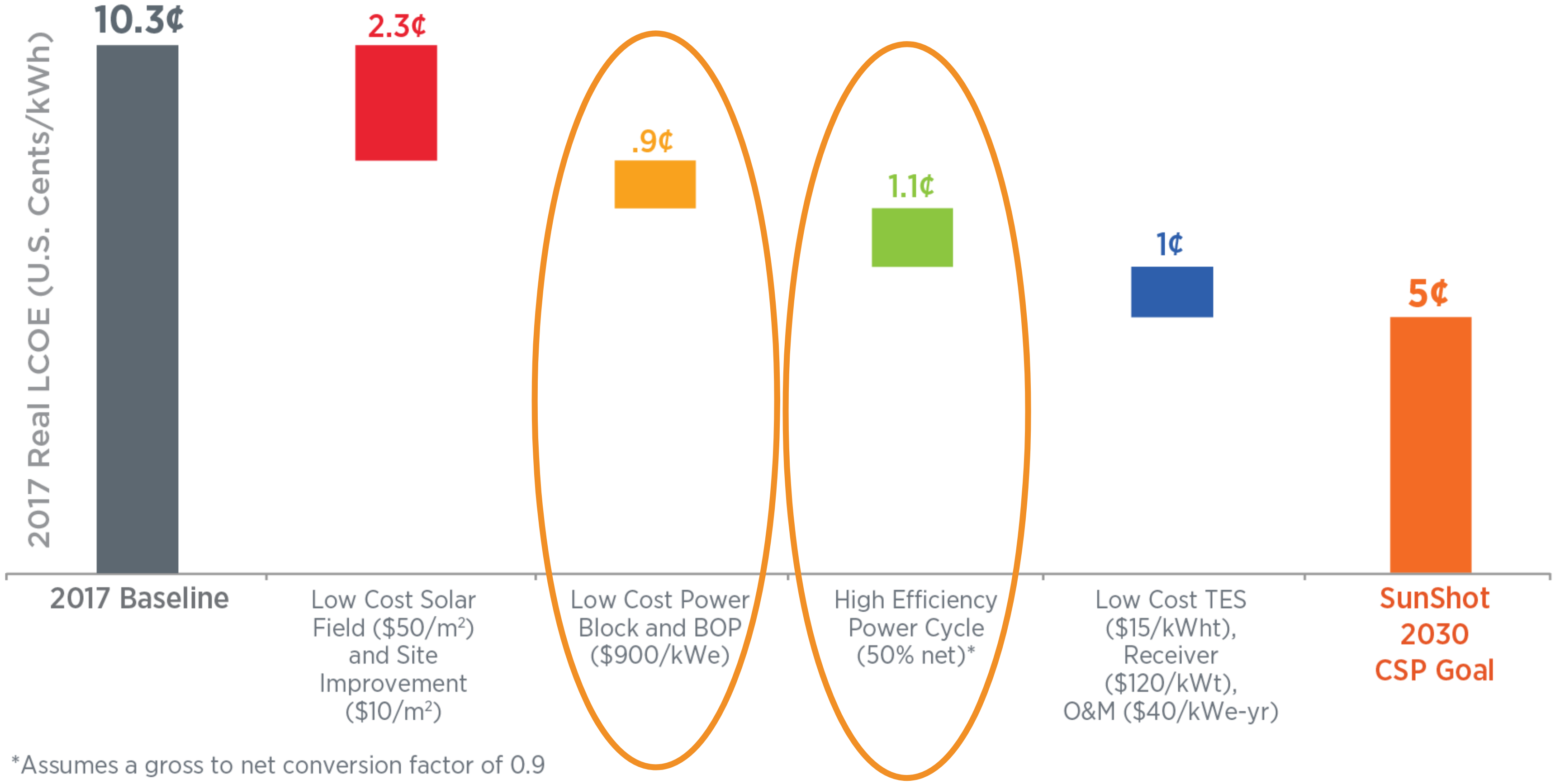
CSP Program Technical Targets



Competitive Programs

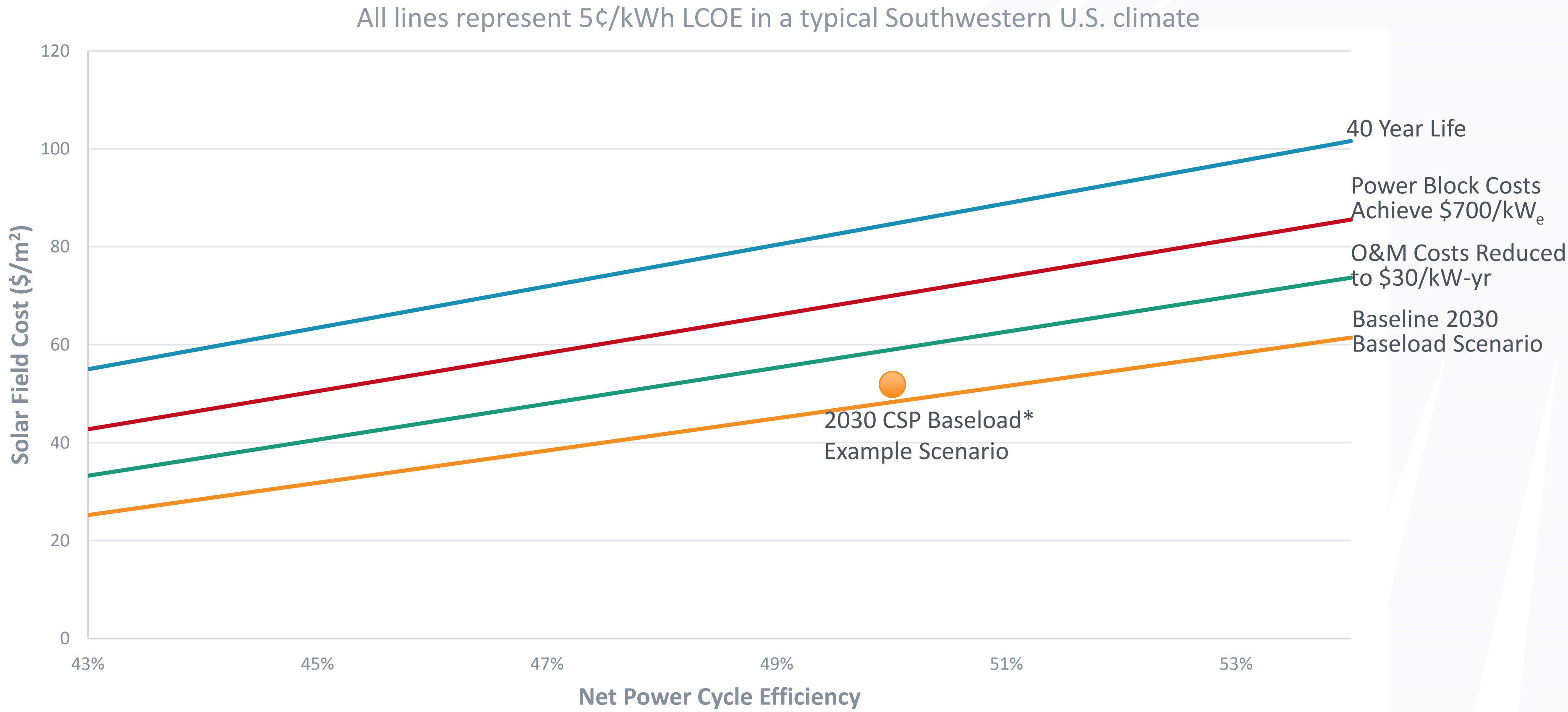
$62M	Gen3 CSP Systems (2017)
$15M	Desalination (2017)
$15M	FY19-21 National Lab Call (2017)
$9M	COLLECTS (2016)
$32M	CSP: APOLLO (2015)
$29M	CSP SuNLaMP (2015)
$1.4M	SolarMat II (2014)
$10M	CSP: ELEMENTS (2014)
$1.1M	SunShot Incubator (Recurring)
$4M	PREDICTS (2013)
$2M	SolarMat (2013)
$10M	CSP-HIBRED (2013)
$27M	National Lab R&D (2012)
$10M	SunShot MURI (2012)
$56M	CSP SunShot R&D (2012)
$0.5M	BRIDGE (2012)
$62M	CSP Baseload (2010)

A Pathway to 5 Cents per KWh for Baseload CSP



*Assumes a gross to net conversion factor of 0.9

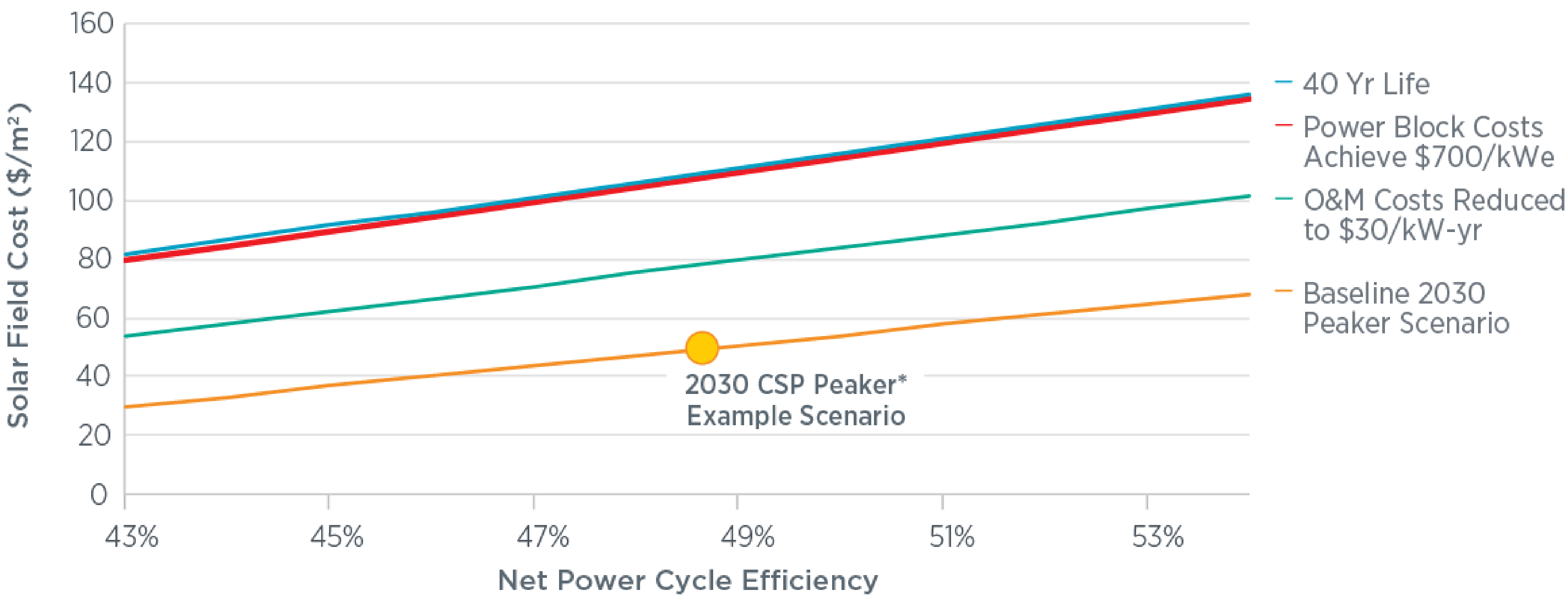
Pathways to Achieving 2030 SunShot Goals



*Baseload power plant is defined as a CSP plant with greater than or equal to 12 hours of storage

Pathways to Achieving SunShot 2030 Goals

All lines represent 10¢/kWh LCOE in a typical Southwestern U.S. climate



*Peaker power plant is defined as a CSP plant with less than 6 hours of storage

Gen3 CSP: Raising the Temperature of Solar Thermal Systems

$$\eta = 1 - \frac{T_C}{T_H}$$

Thermal Pathway	Primary Challenges
Liquids	Reliable corrosion management with advanced molten salts
Solids	High-efficiency transfer of heat in and out of particles
Gas	Integrating low-density gases with cost-effective thermal energy storage

Generation 3 Concentrating Solar Power Systems Funding Opportunity

- Total federal funds available: $62,000,000
- Full Applications were received in January, 2018
- Selections expected to be announced in May of 2018

https://www.osti.gov/scitech/biblio/1338899

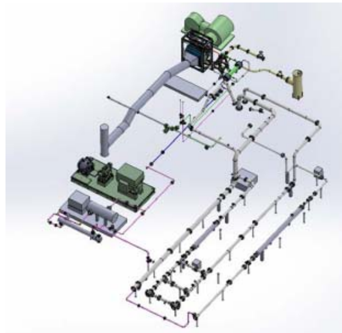
SETO sCO_2 Power Cycle Portfolio by Category

CATEGORY	PROJECT TITLE	PRIME
Turbomachinery	Compression System Design and Testing for sCO_2 CSP Operation	GE
	Development of an Integrally-Geared sCO_2 Compander	SwRI
	Development of High Efficiency Expander and 1 MW Test Loop	SwRI
	Physics-Based Reliability Models for sc-CO_2 Turbomachinery Components	GE
Materials	Lifetime Model Development for Supercritical CO_2 CSP Systems	ORNL
	sCO_2 Corrosion and Compatibility with Materials	UW-Madison
Other Components	Development and Testing of a Switched-Bed Regenerator	UW-Madison
	sCO_2 Power Cycle with Integrated Thermochemical Energy Storage	Echogen Power Systems
Technoeconomics	Cycle Modeling, Integration with CSP, and Technoeconomics	NREL
Primary Heat Exchanger	High Flux Microchannel Direct sCO_2 Receiver	Oregon State
	High-Temperature Particle Heat Exchanger for sCO_2 Power Cycles	SNL
	Robust, Cost-Effective Molten Salt HXer for 800°C Operation with sCO_2	Purdue
	Solar Receiver with Integrated Thermal Storage for sCO_2	Brayton Energy

SETO sCO_2 Power Cycle Portfolio - Turbomachinery

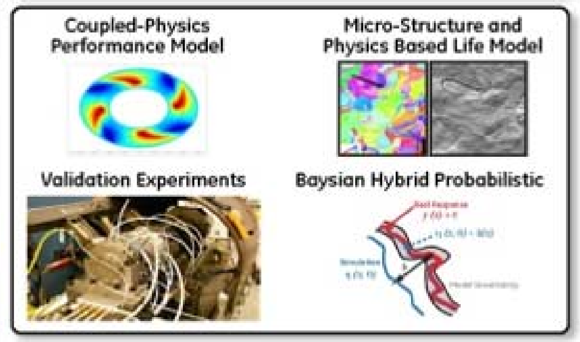
Development of High Efficiency Expander and 1 MW test loop – SunShot (2012)

SwRI
GE
TharEnergy



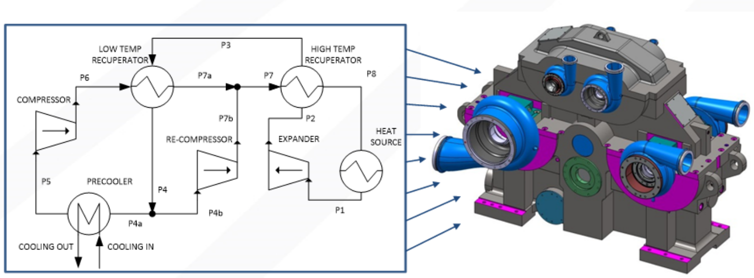
Physics-Based Reliability Models for sc-CO2 Turbomachinery Components– PREDICTS (2013)

GE
SwRI



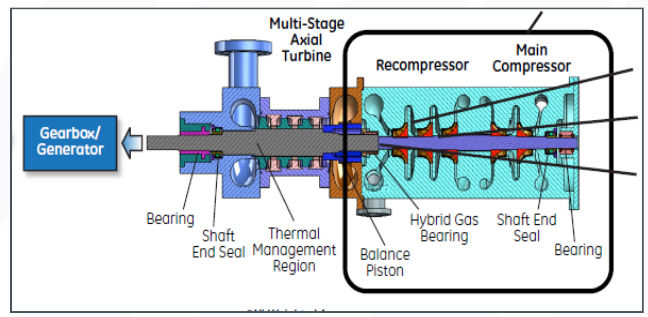
Development of an Integrally-Geared sCO_2 Compander – CSP: APOLLO (2015)

SwRI
Hanwha Techwin



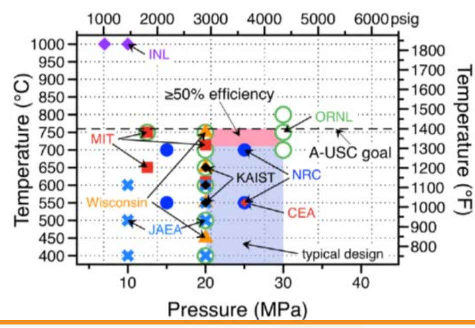
Compression System Design and Testing for sCO_2 CSP Operation– CSP: APOLLO (2015)

GE
SwRI

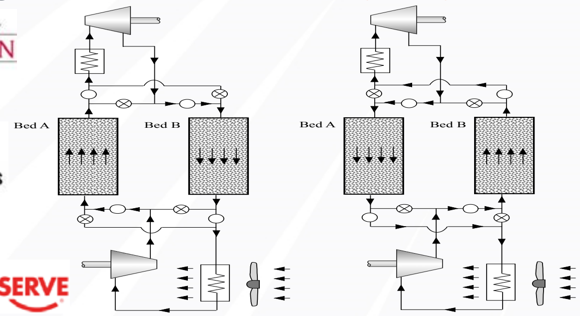


SETO sCO_2 Power Cycle Portfolio – Corrosion and Components

Lifetime Model Development for Supercritical CO2 CSP Systems – SuNLaMP (2015)



Development and testing of a switched-bed regenerator – CSP: APOLLO (2015)



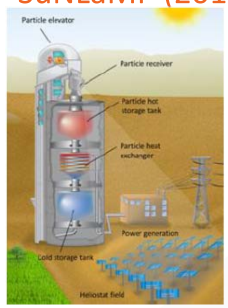
sCO2 corrosion and compatibility with materials – various awards

sCO_2 Power Cycle with Integrated Thermochemical Energy Storage – Tech-to-Market 3 (2017)

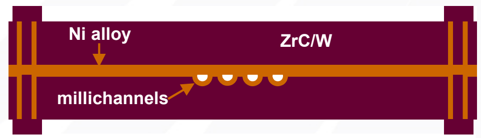
Cycle modeling, integration with CSP, and technoeconomics – SuNLaMP (2015)

SETO sCO_2 Power Cycle Portfolio – Primary Heat Exchanger

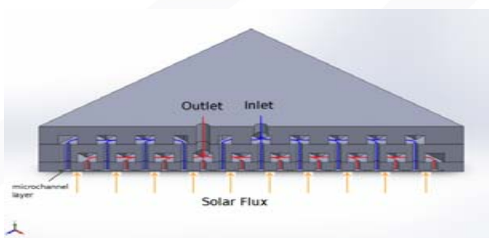
High-Temperature Particle Heat Exchanger for sCO2 Power Cycles – SuNLaMP (2015)



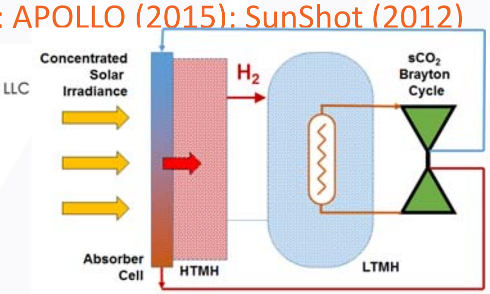
Robust, Cost-Effective Molten Salt HXer for 800 °C Operation with sCO_2 – CSP: APOLLO (2015)



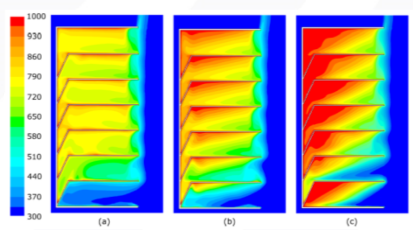
High Flux Microchannel Direct sCO_2 Receiver – CSP: APOLLO (2015); SunShot (2012)



Solar Receiver with Integrated Thermal Storage for sCO2 – CSP: APOLLO (2015); SunShot (2012)



Direct sCO_2 Receiver Development – LPDP (2012)



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Optimizing the Supercritical CO_2 Brayton Cycle for Concentrating Solar Power Application

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Questions?

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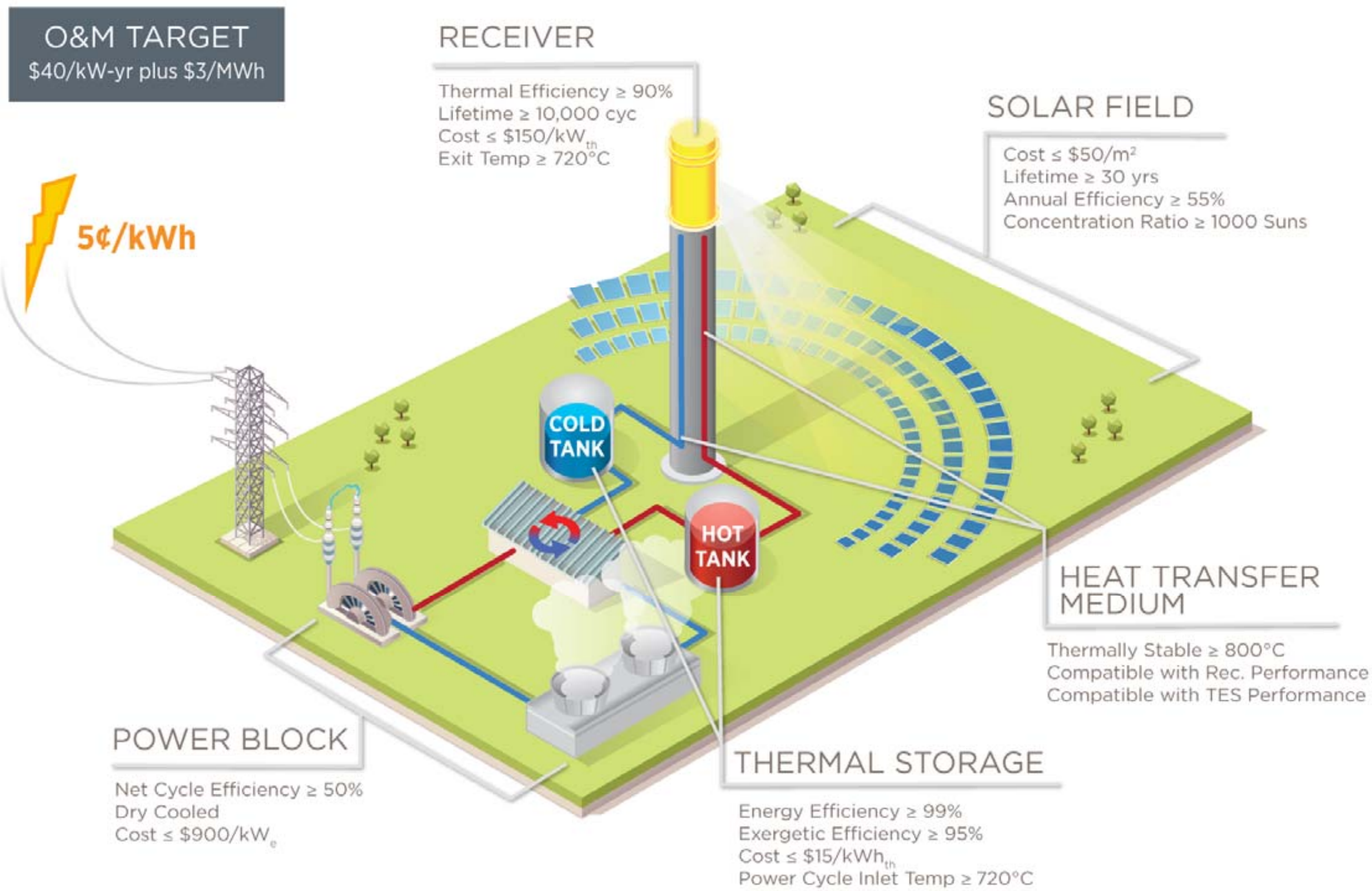
CSP Program Technical Targets



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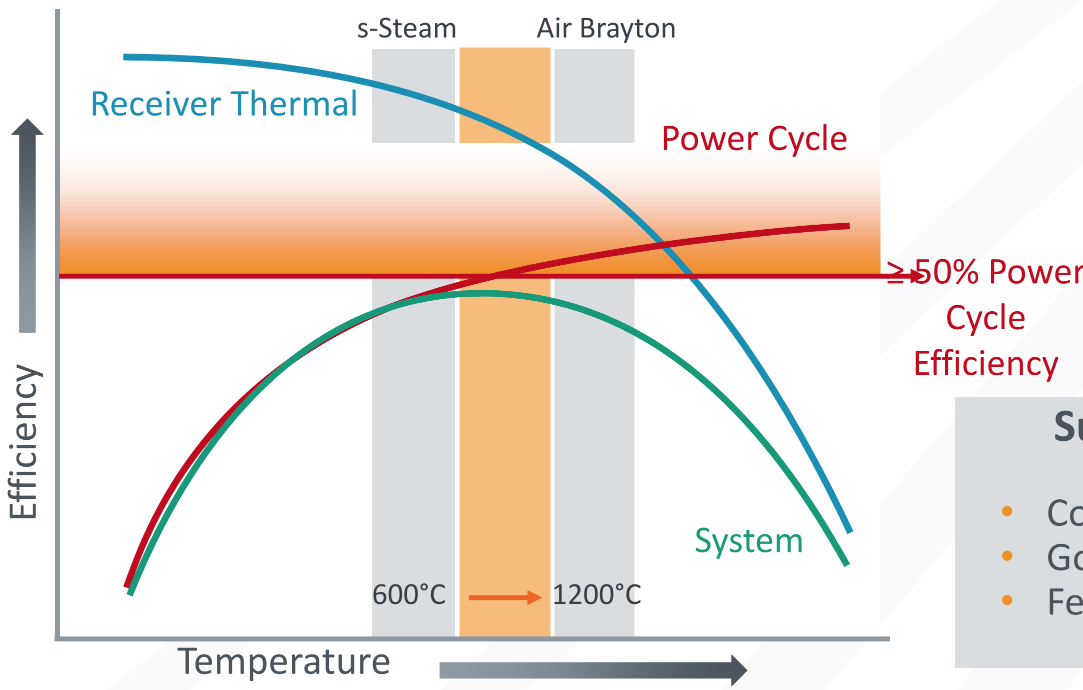
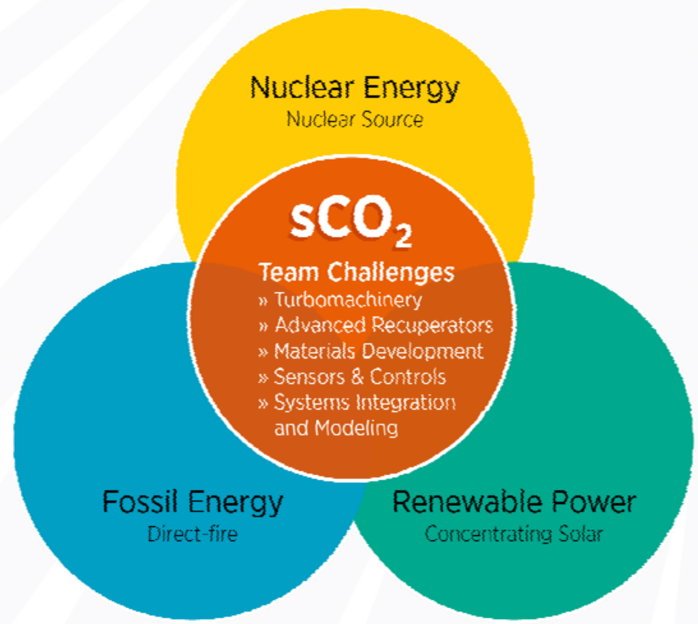
Next Generation CSP will Leverage Next Generation Power Cycles

$$\eta_{Cycle} = 1 - \frac{T_C}{T_H} \quad vs. \quad Q_{Radiative}\ \alpha\ T^4$$





Supercritical CO_2 is a dense, compressible fluid:

- Compact turbomachinery
- Good compatibility with dry cooling
- Fewer loss mechanisms and parasitics