National Renewable Energy Laboratory
Innovation for Our Energy Future

Concentrating Solar Power (CSP) Overview

Mark S. Mehos
CSP Program Manager

National Renewable Energy Laboratory

Golden, CO

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

Outline

- Technology Overview
- U.S. and International Market Overview
- DOE Research and Development

CSP, aka Solar Thermal Power

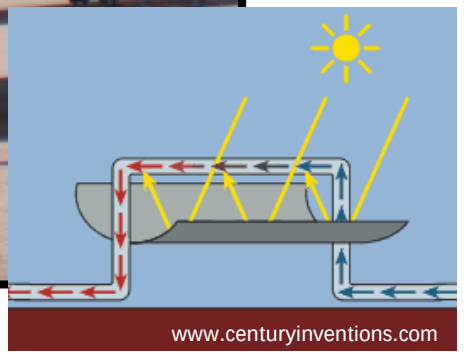
Parabolic trough

Linear Fresnel

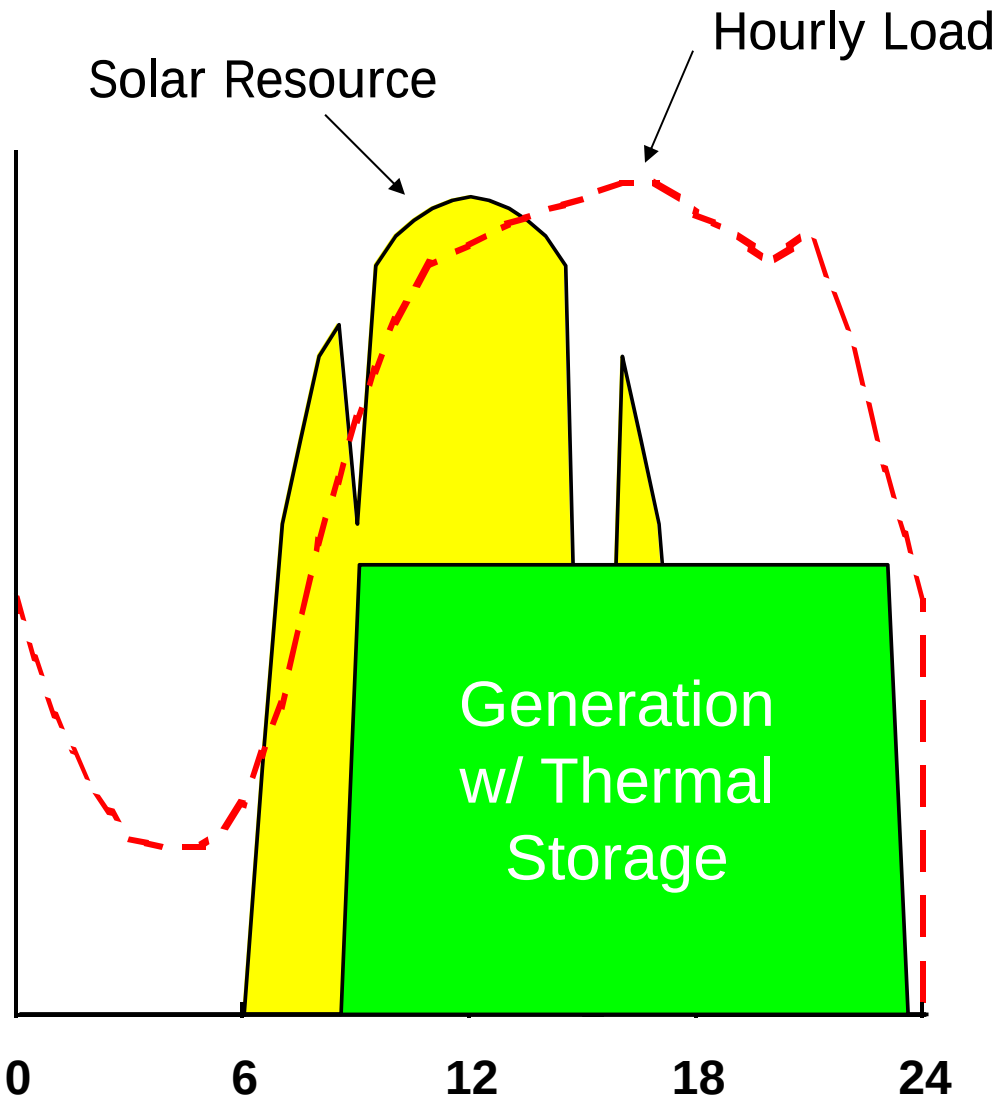
Power tower

Dish/Stirling

Parabolic Trough



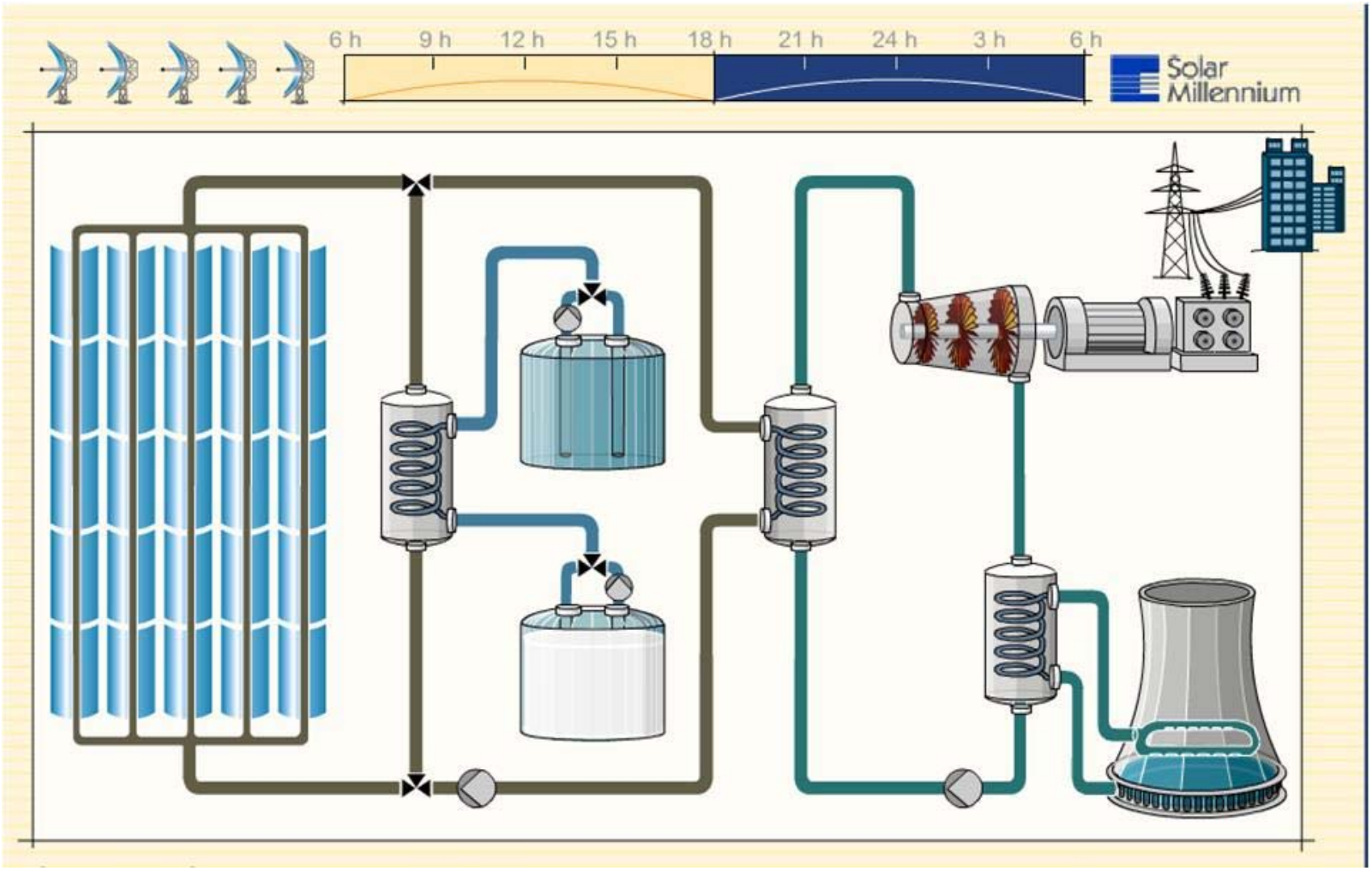
Value of Dispatchable Power?
Meets Utility Peak Power Demands



Storage provides

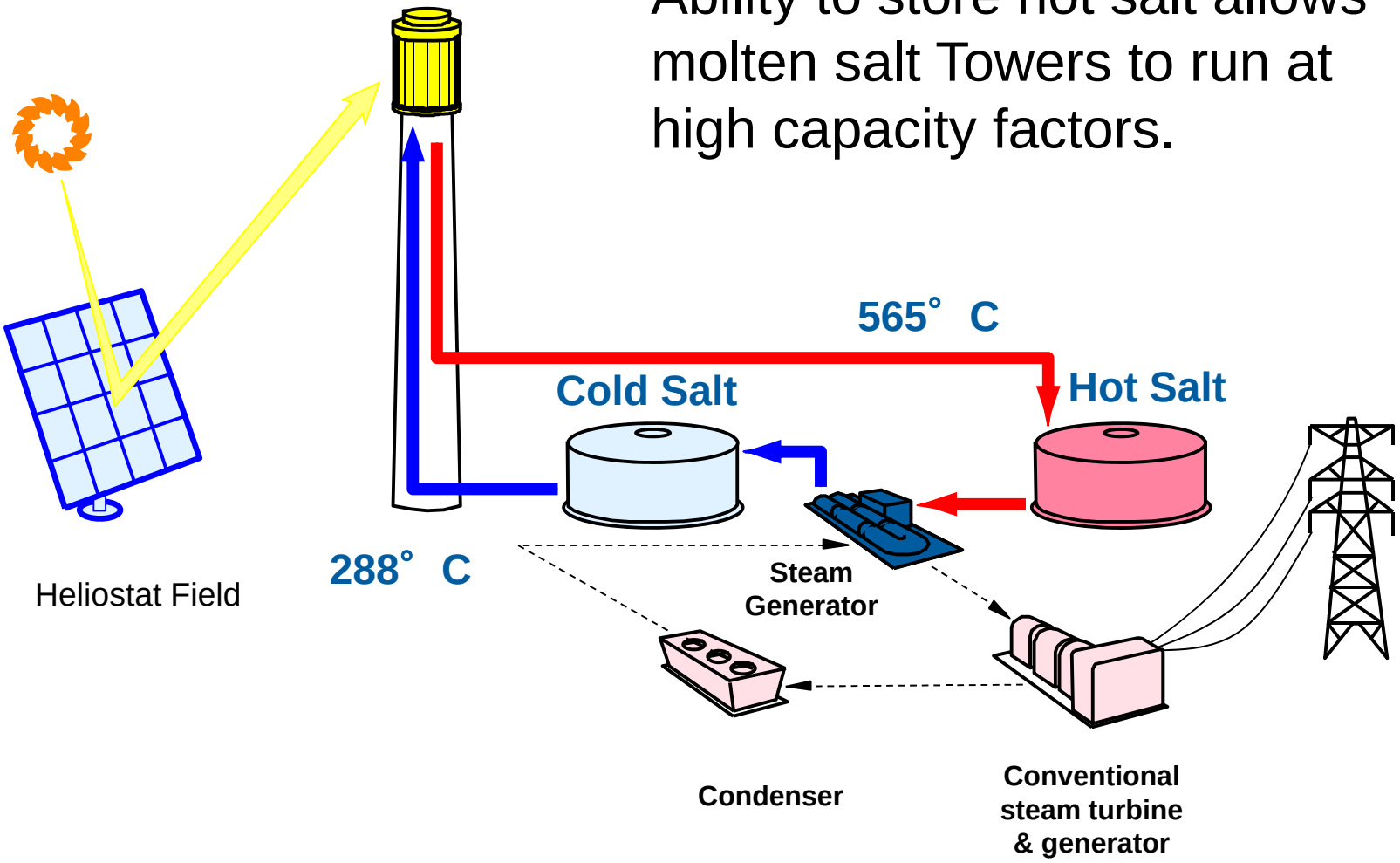
- higher value because power production can match utility needs
- lower energy costs if storage is less expensive than incremental turbine costs

Parabolic Trough Plant

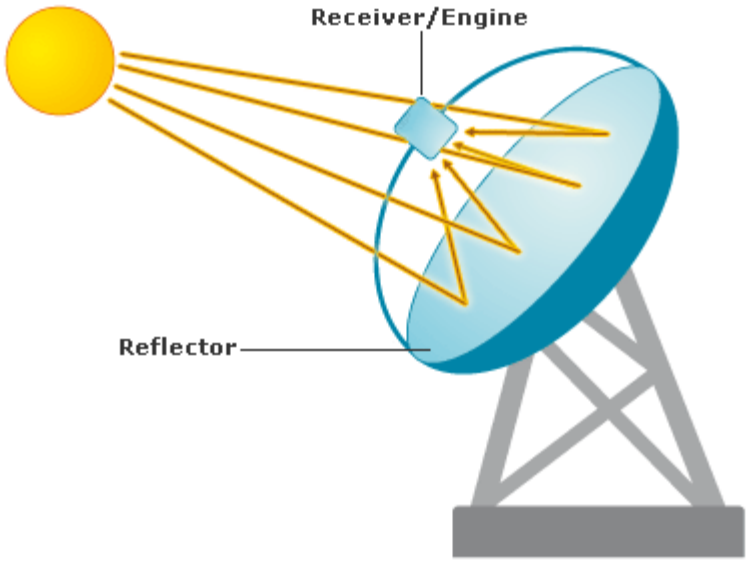


Molten Salt Power Tower

Ability to store hot salt allows molten salt Towers to run at high capacity factors.



Dish/Engine



Parabolic Trough

Design approaches:

- Oil HTF
  - All commercial plants to date
- Molten Salt HTF
  - Archimedes (pilot)
  - Abengoa (R&D)
  - Solar Millennium (R&D)
- Direct Steam HTF
  - Abengoa (R&D)

Power Tower (Central Receiver)

Design approaches:

- Direct Steam HTF
  - Abengoa PS10/PS20
  - BrightSource (pilot)
  - eSolar (pilot)
- Molten Salt HTF
  - Solar One (pilot)
  - Gemasolar (under construction)
  - SolarReserve
- Air HTF
  - Jülich (pilot)

Dish/Engine & Concentrating PV

Dish/Stirling: Pre-commercial, pilot-scale deployments

Concentrating PV: Commercial and pre-commercial pilot-scale deployments

- Modular (3-25kW)
- High solar-to-electric efficiency
- Capacity factors limited to 25% due to lack of storage capability

Technology Comparison

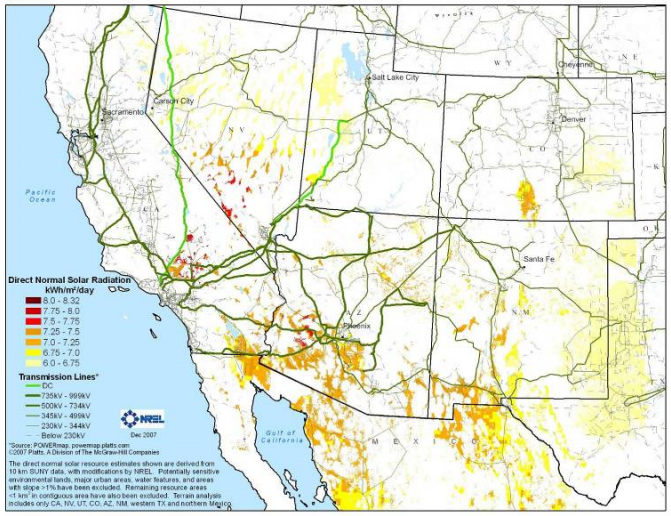
	Trough	Power Tower	Dish / Engine	PV
Typical Operating Temp	390C	565C	800C	n/a
Utility scale (>50 MW)	x	x	x	x
Distributed (<10MW)			x	x
Energy Storage	x	x		
Water use for cleaning	x	x	x	x
Water use for cooling	preferred	preferred		
Land Use (acre/MW)*	5-9	3-9	8-9	5-9
Land Slope	<3%	<5%	<5%	<5%
Technical maturity	medium	low	low	low to high

* Dependent on location and if storage included, values shown based on plants or announced projects

- Technology Overview
- U.S. and International Market Overview
- DOE Research and Development

CSP Market Goals

– Competitive in southwest intermediate load power markets ($0.12/kWh nominal LCOE) by 2017



– Expand access to include carbon constrained baseload power markets ($0.10/kWh nominal LCOE) by 2020

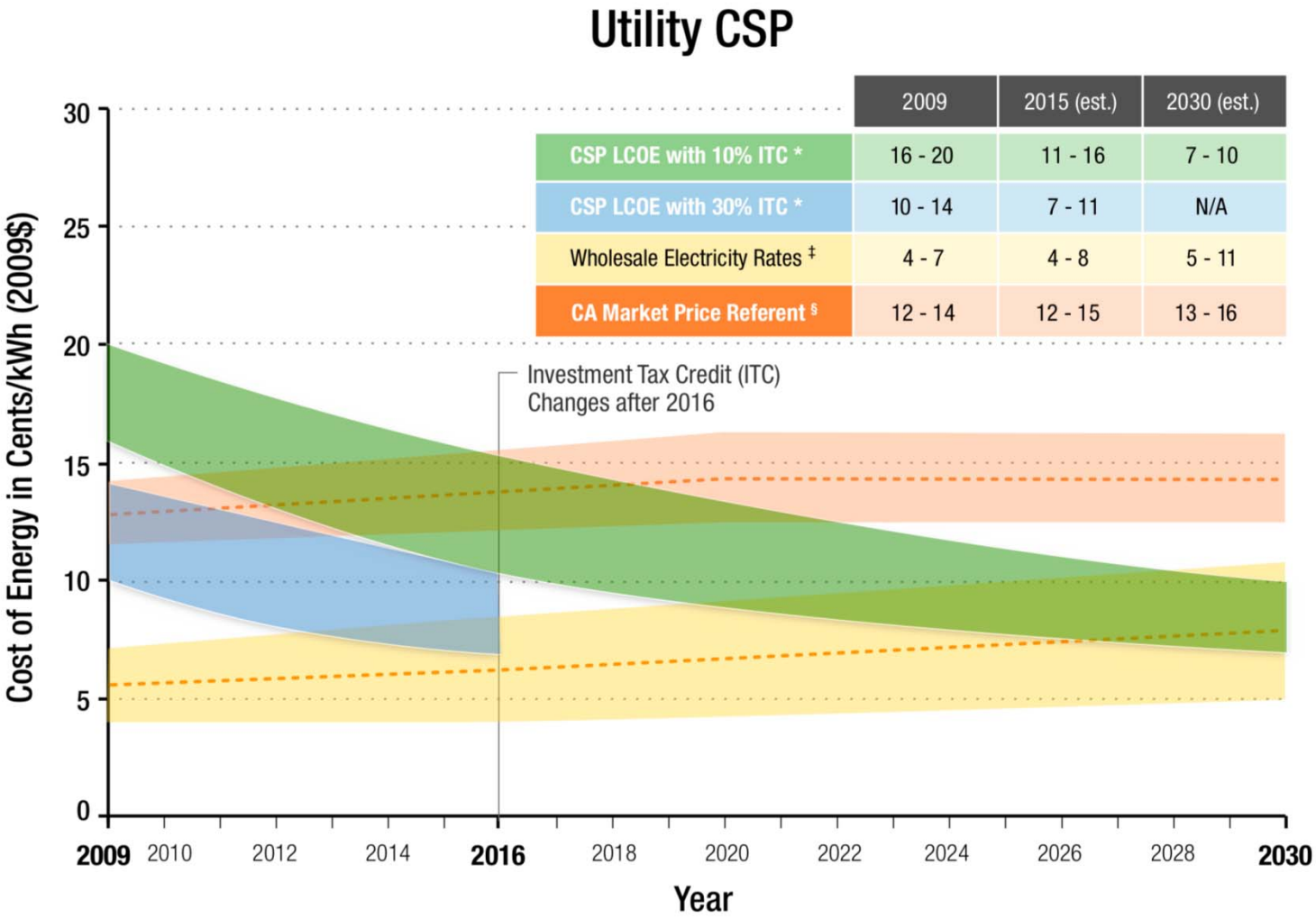
Utility CSP: LCOE Targets, DOE analysis

2015

- With the 30% ITC, CSP is below the CA MPR under all conditions and competitive with high wholesale electricity rates under the best financing conditions
- With the 10% ITC, CSP is equal to the CA MPR under almost all conditions

2030

- With the 10% ITC, CSP is broadly competitive with wholesale electricity rates under all conditions



* Assumes IOU or IPP ownership of CSP, and thus the LCOE includes the taxes paid on electricity generated. Includes 5-year MACRS but not state or local incentives. The range in utility CSP LCOE is due to different technologies, capacity factors and financing conditions. For a complete list of assumptions, see DOE Solar Cost Targets (2009 – 2030), in process.

‡ The electricity rate range represents one standard deviation below and above the mean U.S. wholesale electricity prices.

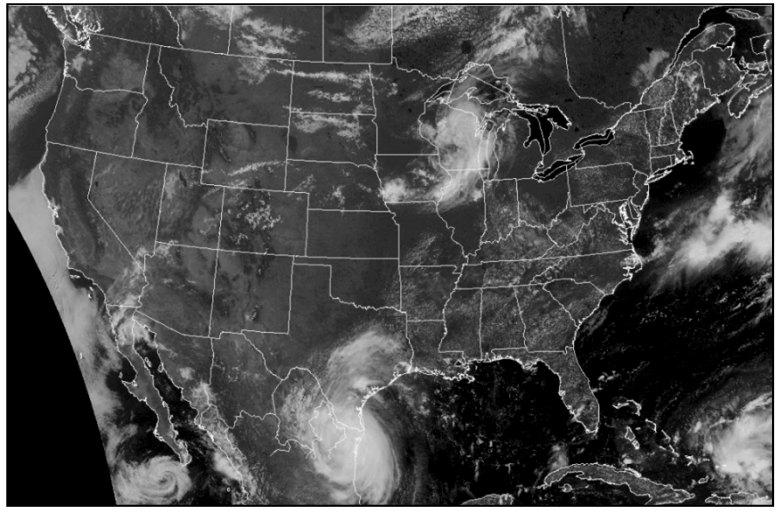
§ The 2009 CA MPR includes adjustments by utility for the time of delivery profile of solar (low case: SDG&E, mid case: PG&E, high case: SCE).

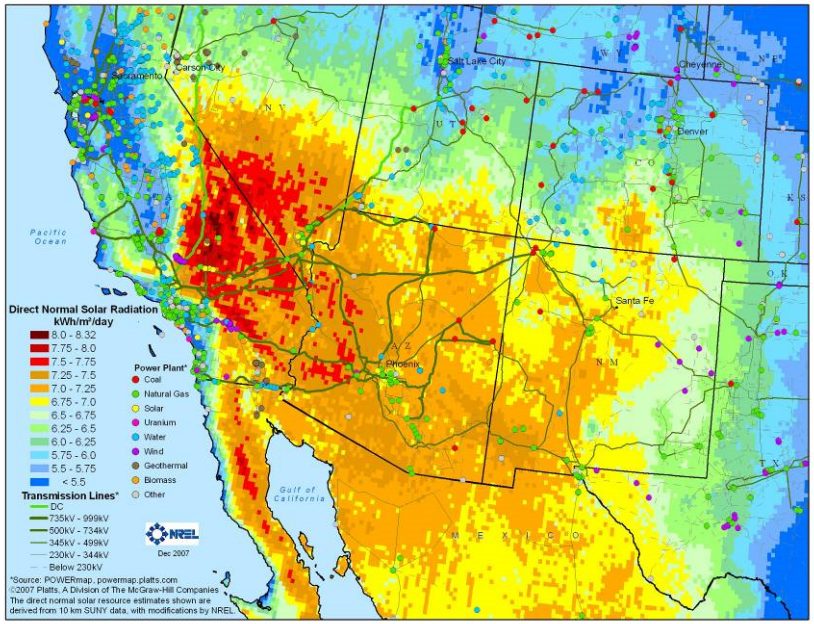
U.S. Southwest GIS Screening Analysis for CSP Generation

Screening Approach

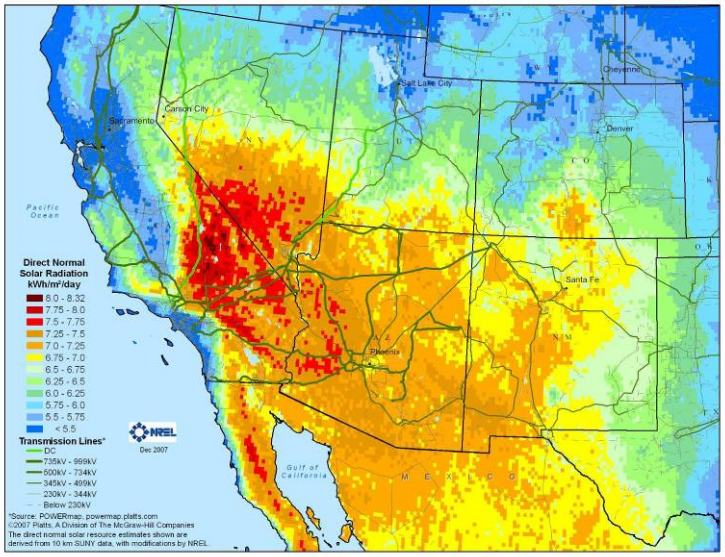
- Initial solar resource and GIS screening analysis used to identify regions most economically favorable to construction of large-scale CSP systems

- GIS analysis used in conjunction with transmission and market analysis to identify favorable regions in the southwest

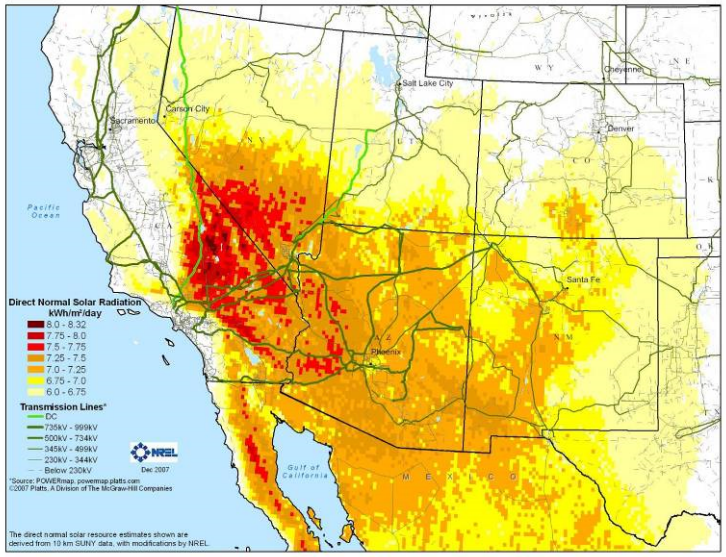




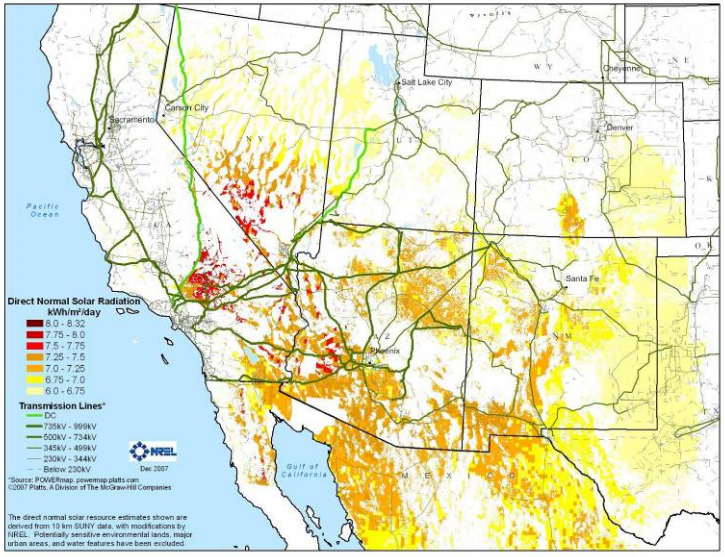
Solar Resource Screening Analysis



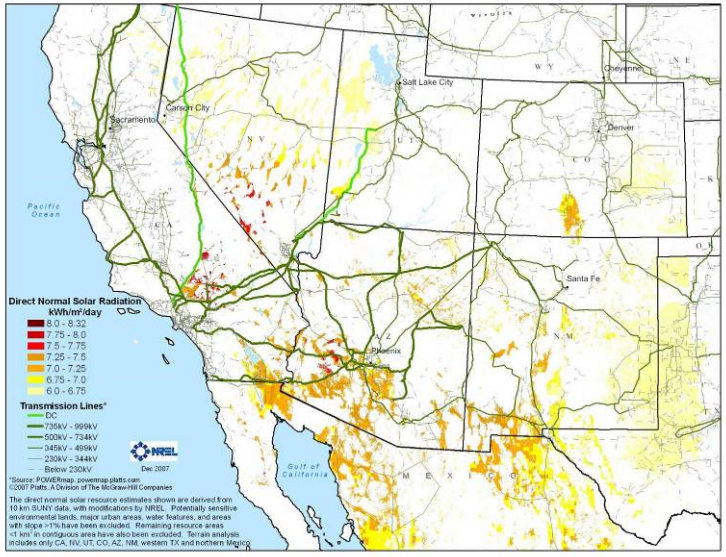
Unfiltered Resource



Solar > 6.0 kwh/m^2-day

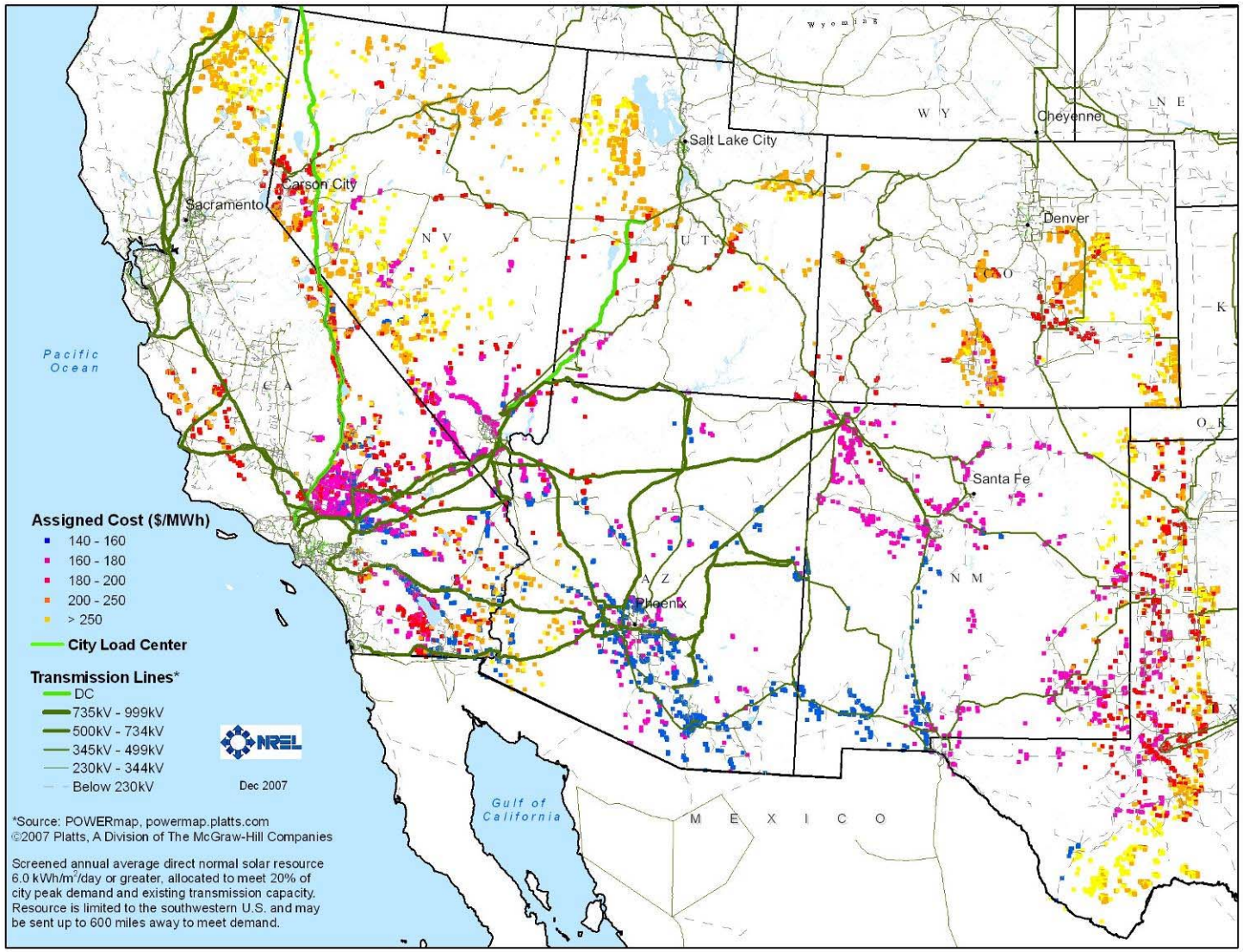


Land Exclusions

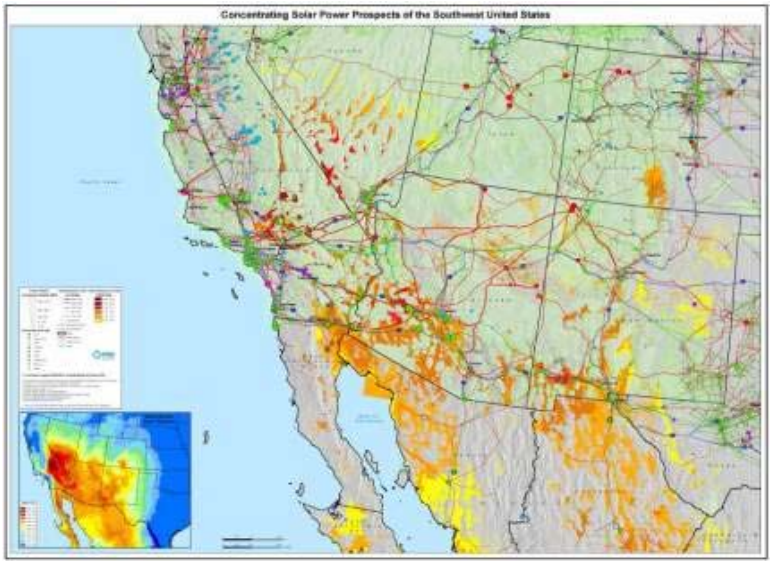


Slope Exclusions

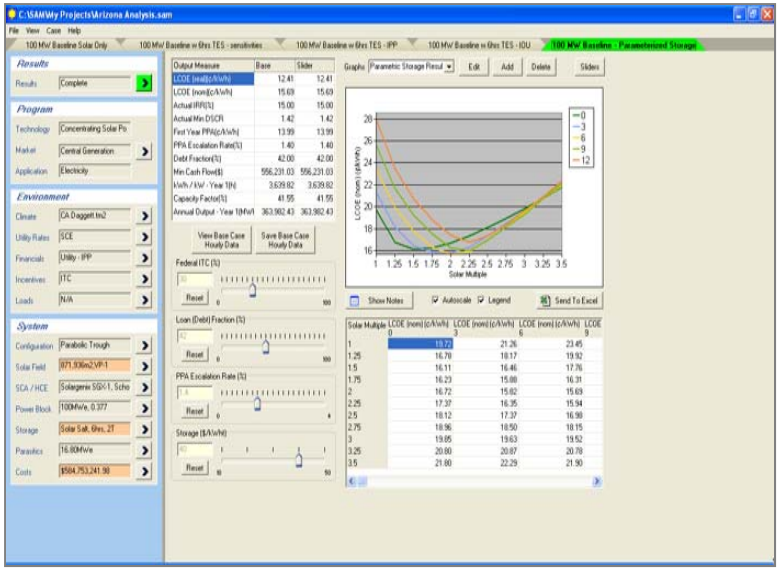
Optimal CSP Sites – Transmission and Resource



Analysis Products

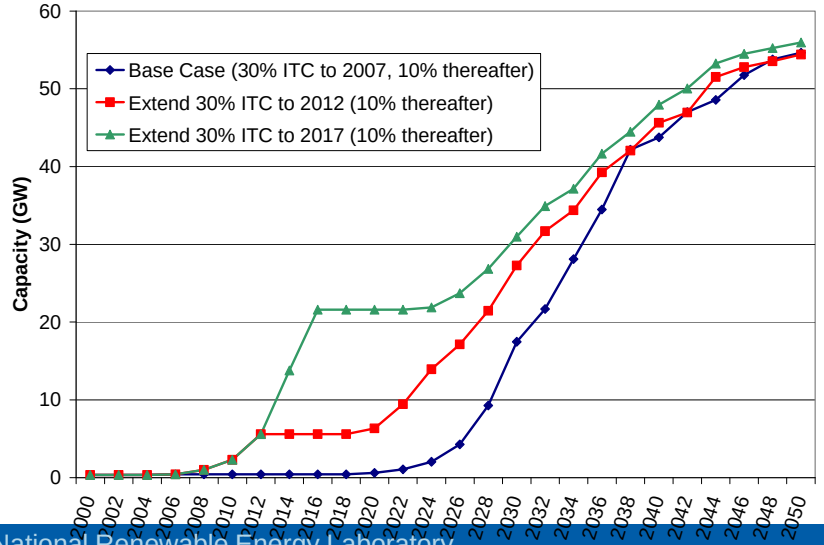


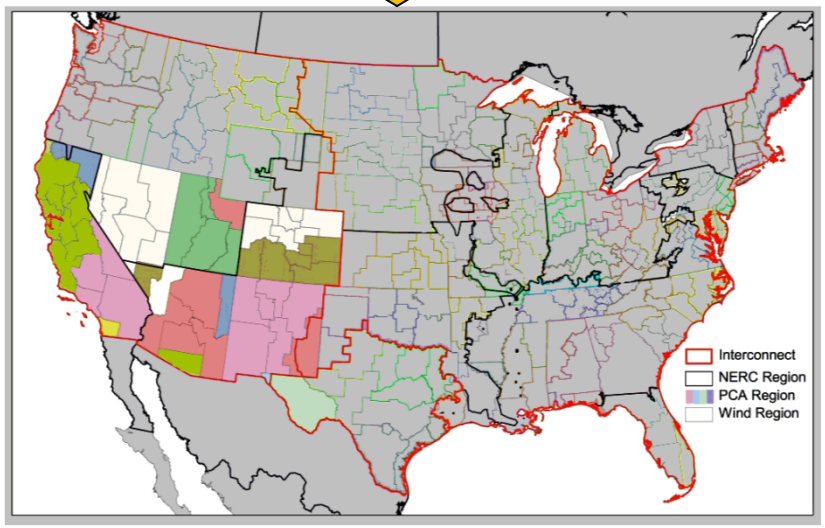
Resource Characterization



Systems Analysis

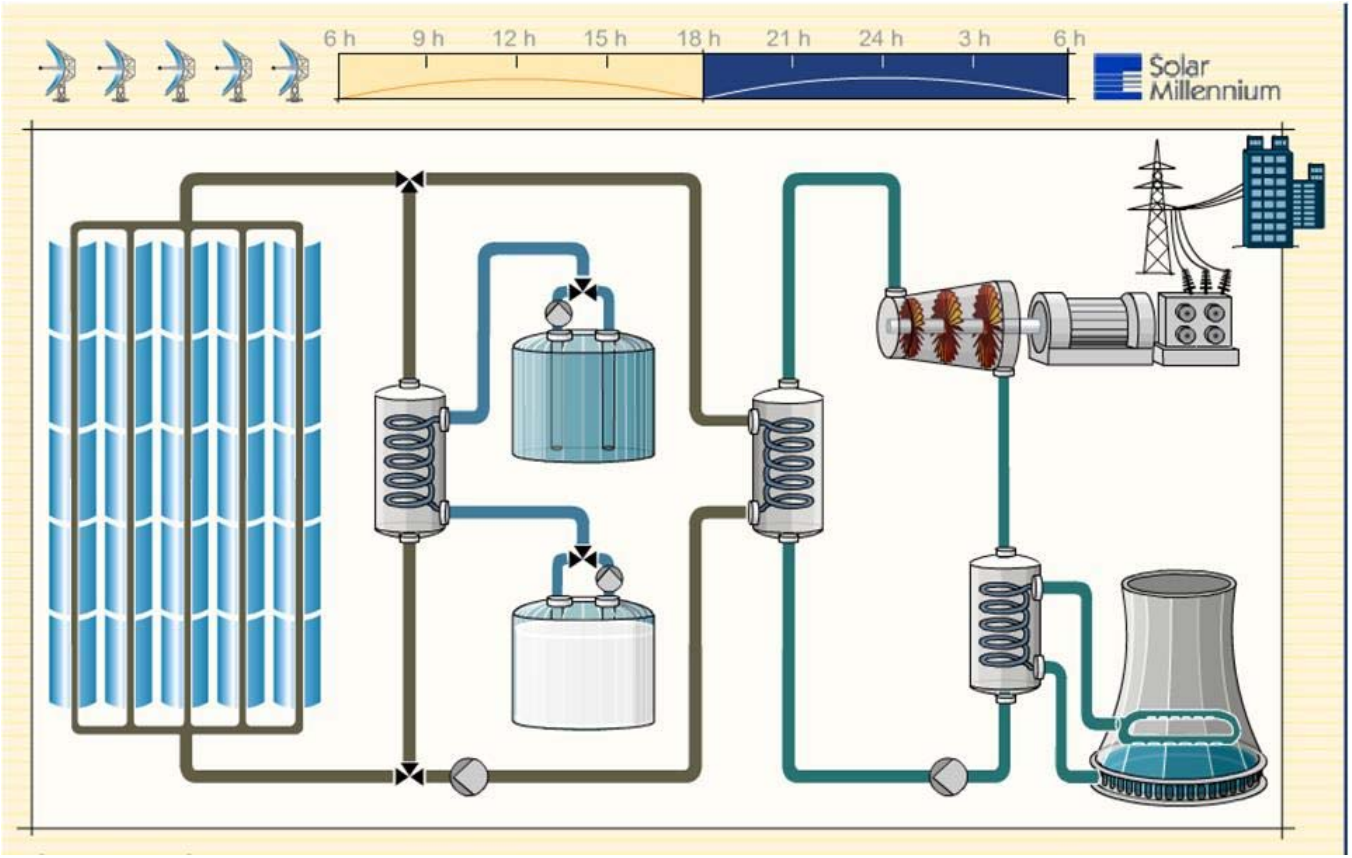
Market Analysis





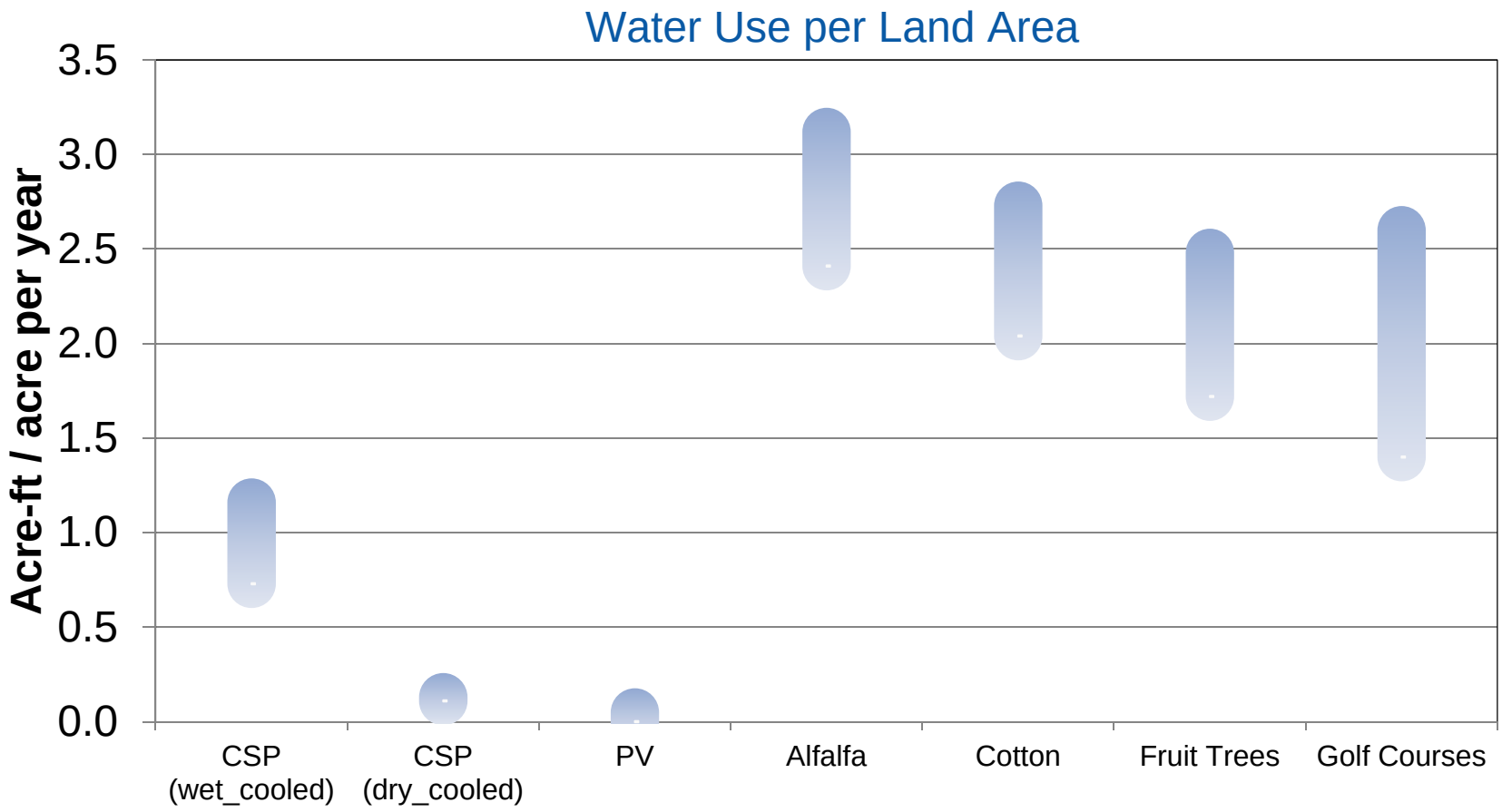
Water Use

Many power plants (including most CSP) use a Rankine steam power cycle to make electricity.



Rankine power cycles require cooling to condense the steam for reuse.

CSP Water Use



Sources:
CSP: Reducing Water Consumption of CSP Electricity Generation, Report to Congress 2009.
Crops: Blaney, Monthly Consumptive use of Water by Irrigated Crops & Natural Vegetation, 1957.
Golf : Watson et al., The Economic Contributions of Colorado's Golf Industry: Environmental Aspects.

354 MW Luz Solar Electric Generating Systems (SEGS) Nine Plants built 1984 - 1991

64 MWe Acciona Nevada Solar One
Solar Parabolic Trough Plant

50 MW AndaSol One and Two
Parabolic Trough Plant w/ 7-hr Storage, Andalucía

Abengoa 50MW Trough Plants
Seville, Spain

50 MW Iberdrola Energia Solar de Puertollano
Puertollano (Ciudad Real)

Abengoa PS10 and PS 20, Seville, Spain

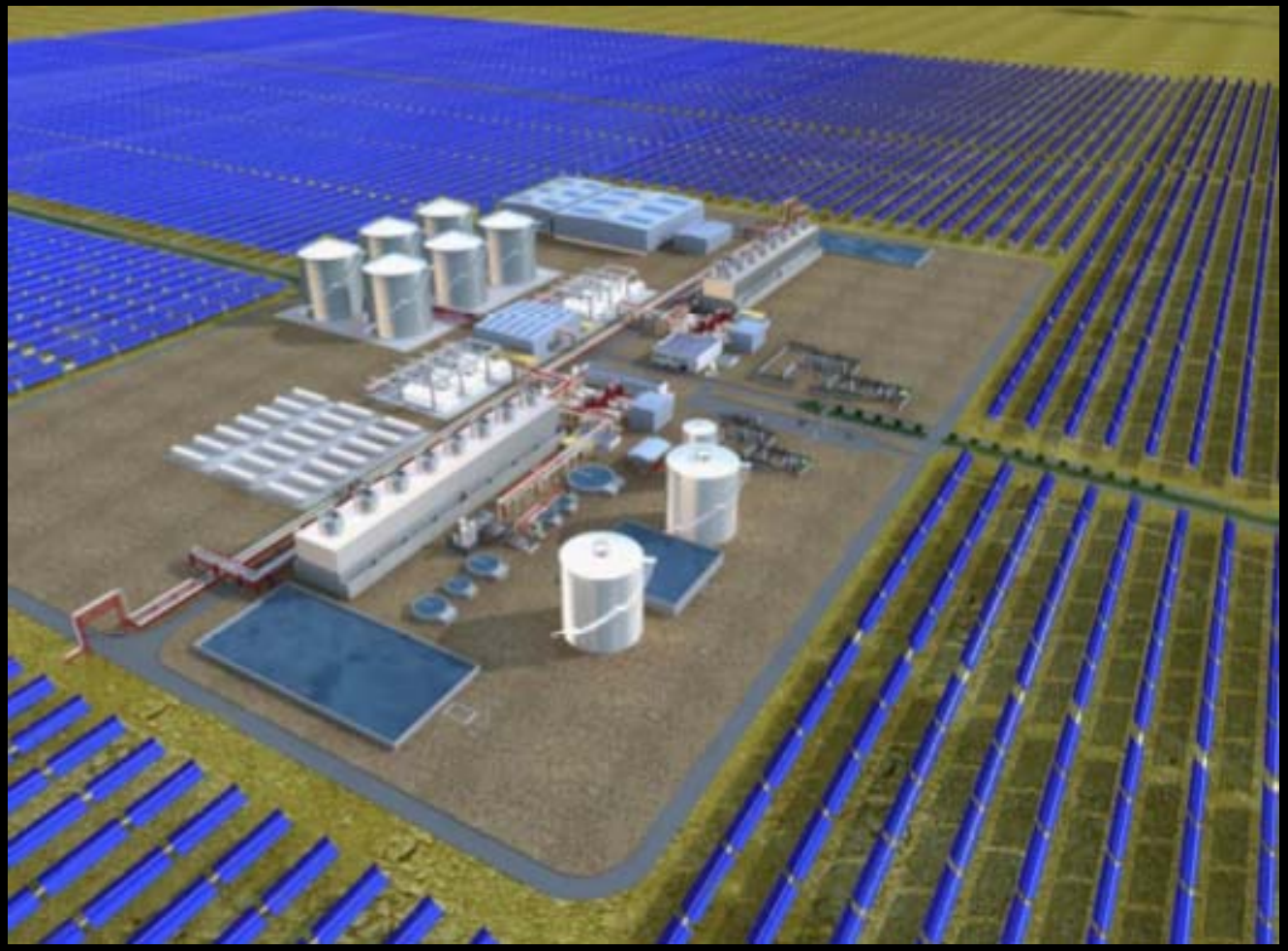
Power Tower Pilot Plants

6 $MW_{thermal}$ BrightSource
Negev Desert, Israel

5 MWe eSolar
California, USA

1MW Dish Demonstration – Phoenix, AZ

Planned 280 MW Solana Plant with 6 hrs Storage



Artist Rendition

2 x 140MW parallel turbine trains

Solar multiple of approximately 2.0 (3 mi^2 solar field)

APS
Renewable Energy

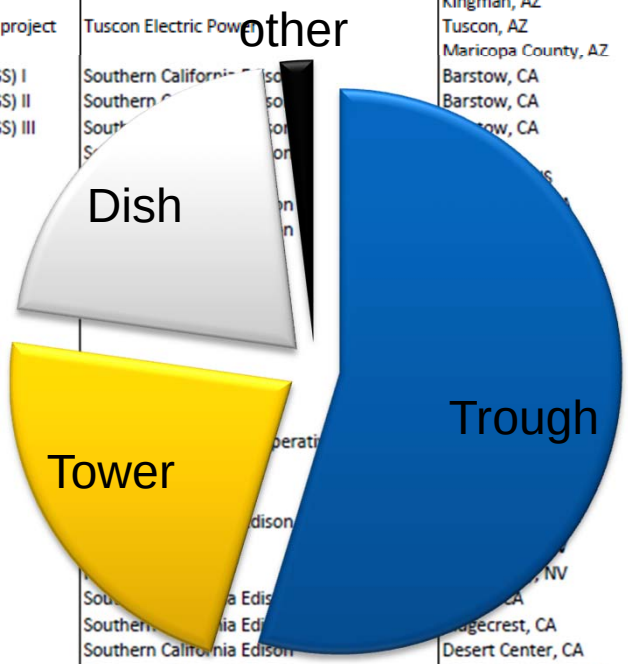
U.S. CSP Projects Under Development
Source: SEIA

Projects Under Development: Concentrating Solar Power (including Concentrating Photovoltaic)

Developer	Project Name	Electricity Purchaser	Location	Technology	Capacity (MW)
Abengoa Solar	Mojave Solar	Pacific Gas & Electric	San Bernardino County, CA	Trough	250
Abengoa Solar	Solana	Arizona Public Service	Gila Bend, AZ	Trough	280
Acciona Solar Power	Ft. Irwin Solar Power Project	U.S. Army/surrounding utilities	Ft. Irwin, CA	Trough	980
Albiasa	Kingman project		Kingman, AZ	Trough	200
Bell Independent Power Corp	UA Tech Park thermal storage demonstration project	Tuscon Electric Power	Tuscon, AZ	Trough	5
Boulevard Associates LLC	Sonoran Solar Energy Project		Maricopa County, AZ	Trough	375
BrightSource Energy	Ivanpah Solar Electric Generating System (SEGS) I	Southern Californi	Barstow, CA	Tower	100
BrightSource Energy	Ivanpah Solar Electric Generating System (SEGS) II	Southern C	Barstow, CA	Tower	100
BrightSource Energy	Ivanpah Solar Electric Generating System (SEGS) III	South	ow, CA	Tower	200
BrightSource Energy		S		Tower	1,200
Emcore/SunPeak Power				Lens CPV	200
eSolar	Gaskell Sun Tower (Phase I)			Tower	105
eSolar	Gaskell Sun Tower (Phase II)			Tower	140
eSolar	Santa Teresa New Mexico SunTower			Tower	92
eSolar	Alpine SunTower			Tower	92
Harper Lake, LLC	Harper Lake Solar Plant			Trough	250
Inland Energy, Inc.	Palmdale Hybrid Gas-Solar plant			Trough	50
Inland Energy, Inc.	Victorville Hybrid Gas-Solar plant			Trough	50
NextEra Energy Resources	Beacon Solar Energy Project			Trough	250
NextEra Energy Resources	Genesis Solar Energy Project			Trough	250
Pacific Light & Power	Westside solar project			Trough	10
San Joaquin Solar, LLC	San Joaquin Solar 1			Trough[1]	53
San Joaquin Solar, LLC	San Joaquin Solar 2			Trough[1]	53
SkyFuel	SkyTrough demonstration			Trough	43
Solar Millennium	Amargosa Farm Road Solar Energy Project 1			Trough	242
Solar Millennium	Amargosa Farm Road Solar Energy Project 2		, NV	Trough	242
Solar Millennium	Blythe Solar Power Project	Sou a Edis	CA	Trough	1,000
Solar Millennium	Ridgecrest Solar Power Project	Southern ia Ed	gecrest, CA	Trough	250
Solar Millennium	Palen Solar Power Project	Southern California Edison	Desert Center, CA	Trough	250
SolarReserve	Rice Solar Energy Project	Southern California Edison	Riverside County, CA	Tower	150
Solel	Mojave Solar Park	Pacific Gas & Electric	Mojave Desert, CA	Trough	553
Tessera Solar	SES Solar One	Southern California Edison	Victorville, CA	Dish-engine	850
Tessera Solar	SES Solar Two	San Diego Gas & Electric	Imperial County, CA	Dish-engine	750
Tessera Solar	SES Solar Three		Imperial County, CA	Dish-engine	550
Tessera Solar	Western Ranch	CPS Energy	San Antonio, TX	Dish-engine	27
Tonopah Solar Energy, LLC	Crescent Dunes Solar Energy Project	NV Energy	Nye County, NV	Tower	180
	New Mexico CSSP	Public Service of New Mexico	NM	Trough	70

(1) Hybrid solar plants cofiring with other fuels (output reflects peak solar contribution)

Concentrating Solar Power Total (MW) ***10,443***



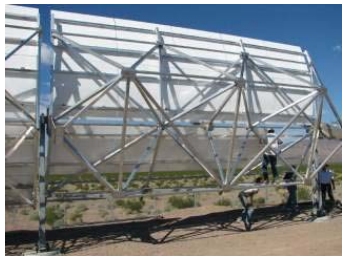
Discussion

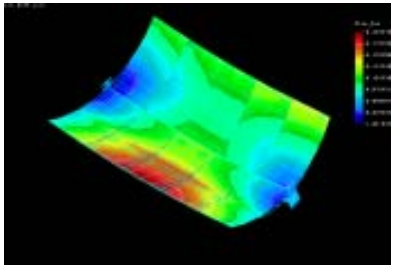
- Technology Overview
- U.S. and International Market Overview
- DOE Research and Development

Technology/Market Support Activities

Concentrator/receiver R&D

- optimize receiver and concentrator designs
- develop next-generation collector designs
- create advanced evaluation capabilities



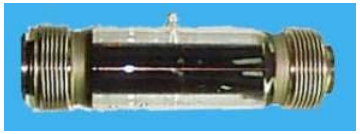


Advanced Thermal Storage

- develop advanced heat transfer fluids for more efficient operation at high temperatures
- analyze and test innovative designs for low-cost storage options

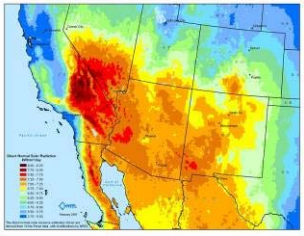
Advanced CSP Concepts and Components

- develop, characterize, and test advanced reflector and absorber materials
- develop and test advanced system components and cycles



CSP Market Transformation

- conduct market penetration analyses
- resource measurement and forecasting
- CSP benefits / impacts analyses



Thank you!

For more information see:

http://www.nrel.gov/csp/

http://maps.nrel.gov/

http://solareis.anl.gov/

Craig Turchi

Concentrating Solar Power Program

303-384-7565

craig.turchi@nrel.gov