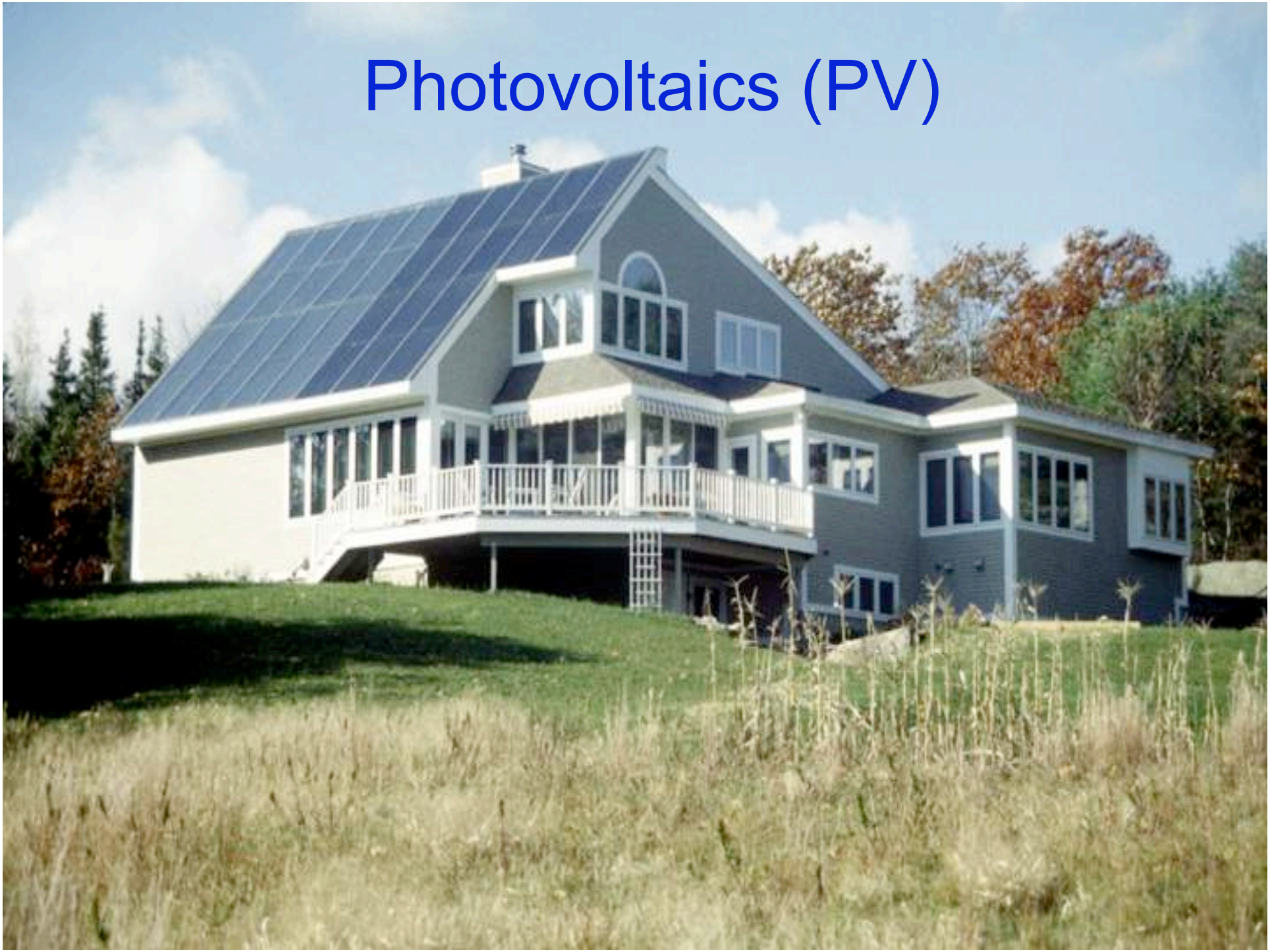
Concentrating Solar Power

Summer School on Global Sustainability
July 20, 2009

Chuck Kutscher
National Renewable Energy Laboratory

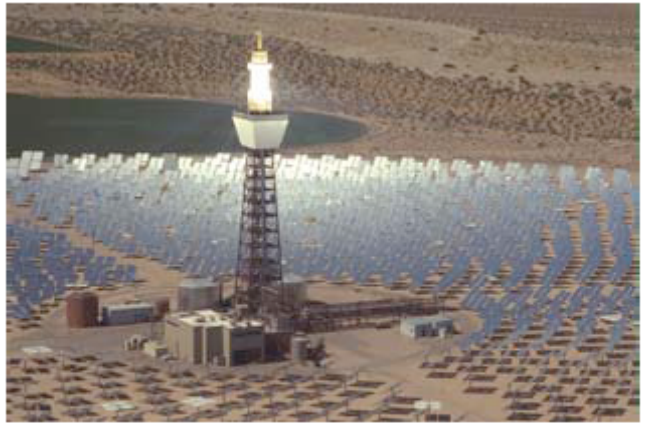
Photovoltaics (PV)



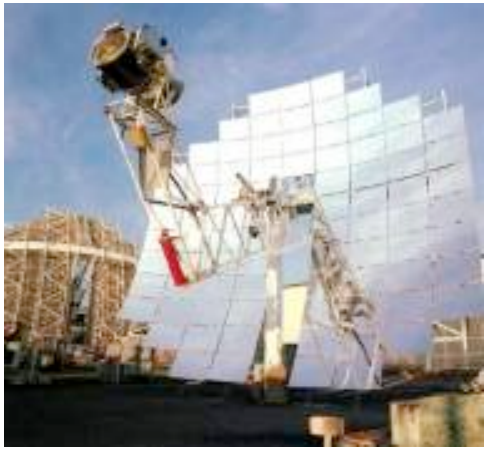
CSP: The Other Solar Energy

Parabolic trough

Linear Fresnel

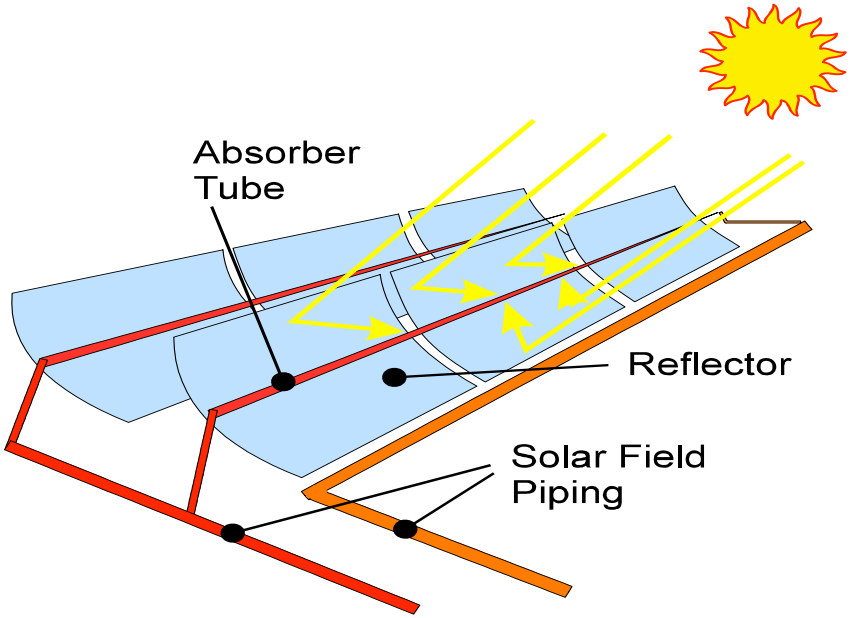


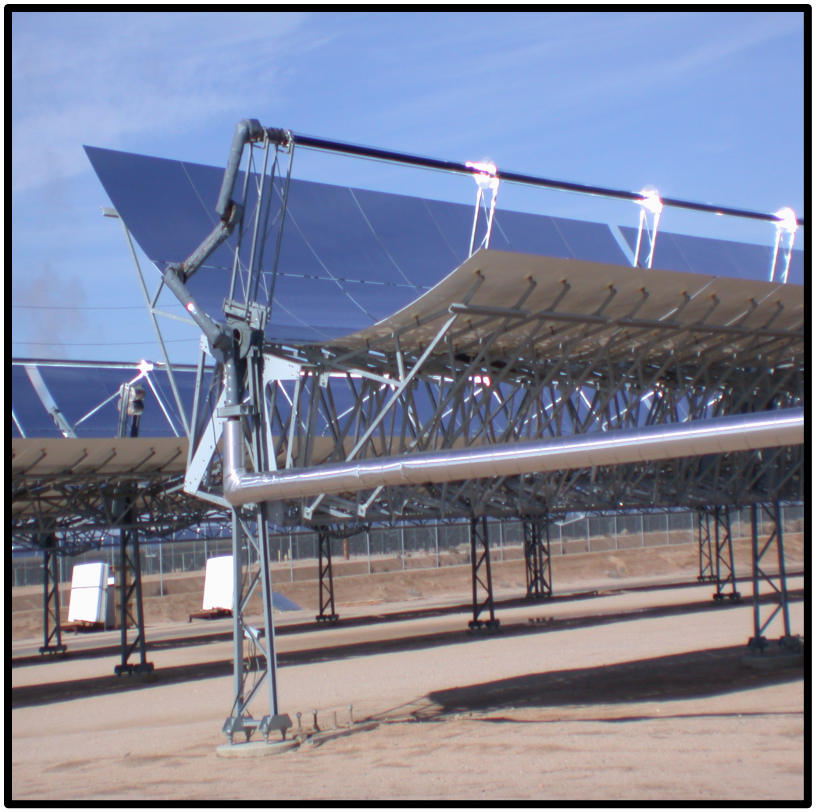
Power tower



Dish-Stirling

Parabolic Troughs

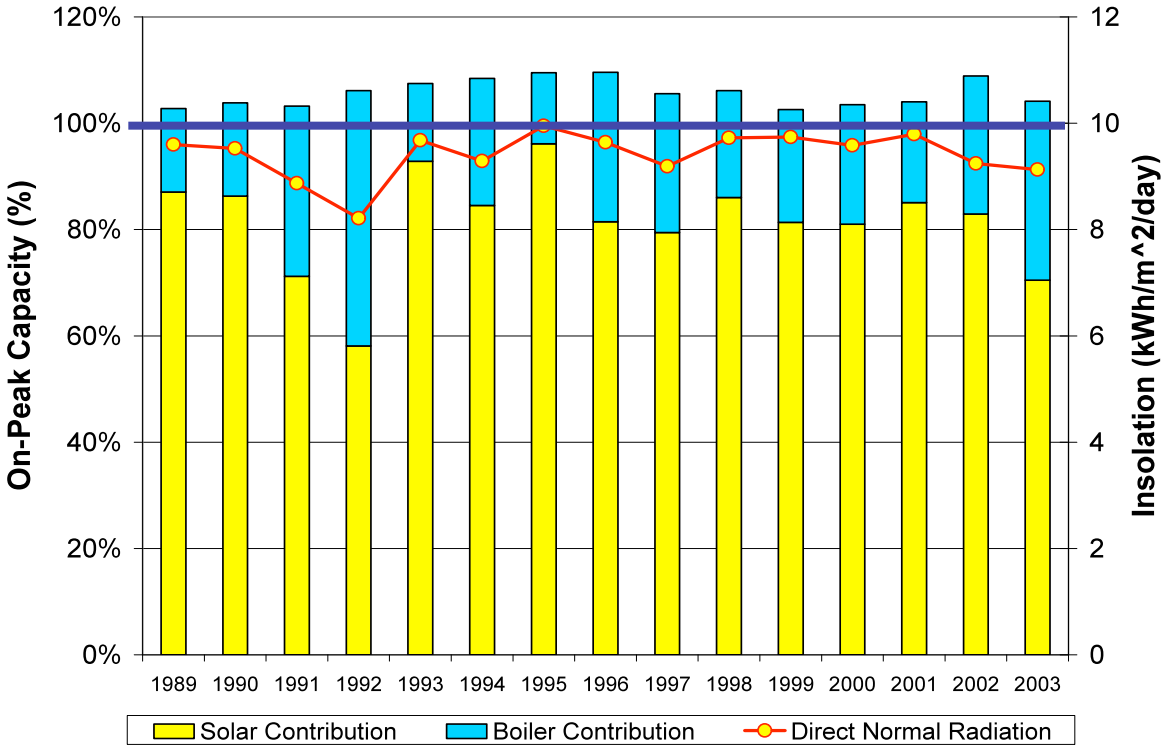




354 MW Luz Solar Electric Generating Systems (SEGS) 1984 - 1991

SEGS Historic Plant Capacity Value

On-Peak Performance
For 5 Parabolic Trough Plants



- Over 100% capacity with fossil backup
- Averaged 80% on-peak capacity factor from solar

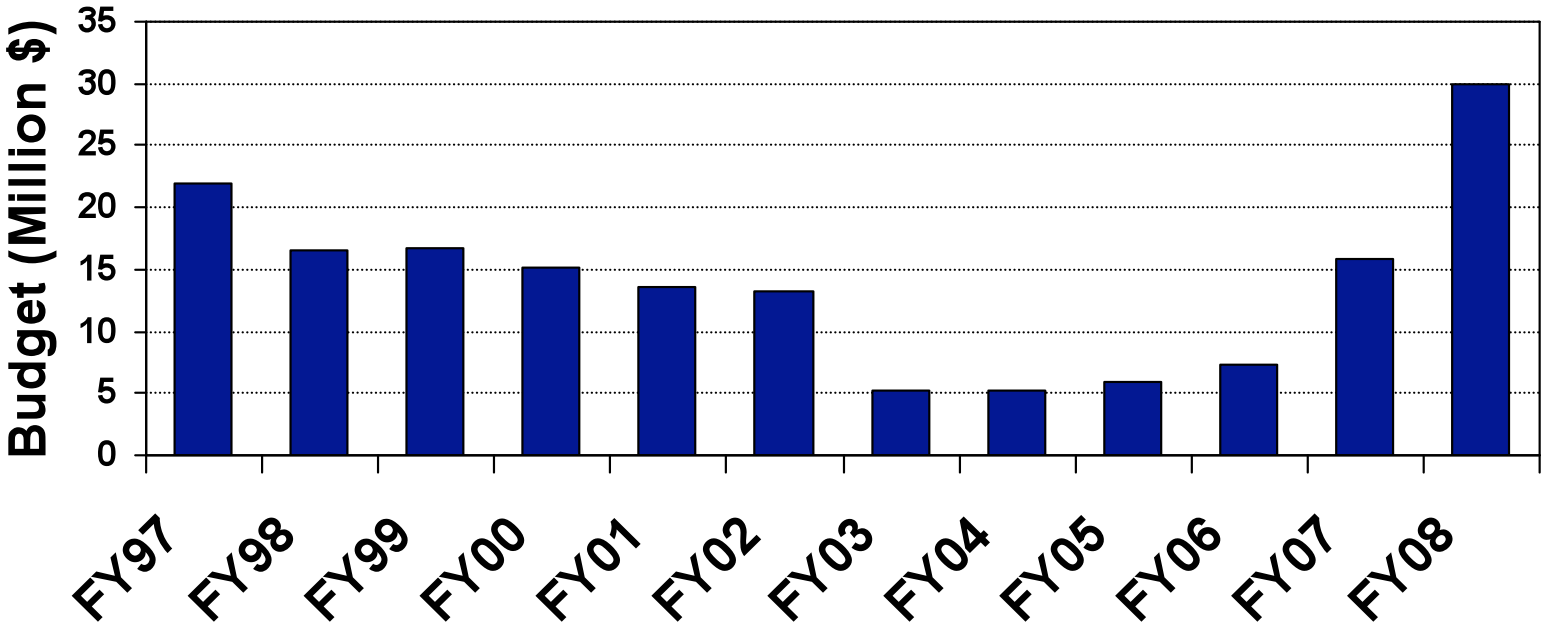
SCE Summer On-Peak
Weekdays: Jun - Sep
12 noon - 6 pm

Source: KJC Operating Company

Why the Decline in Interest?

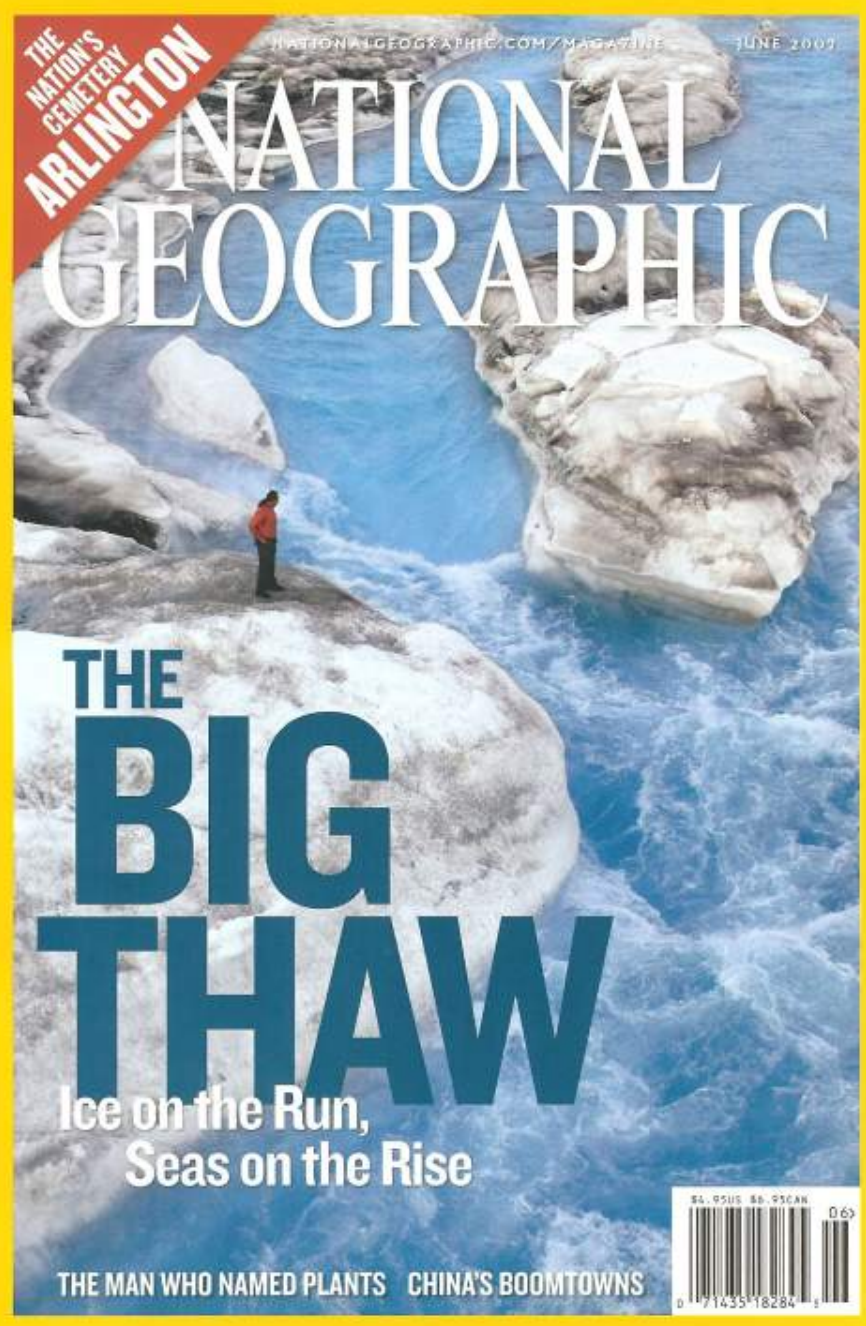
- Low natural gas prices
- Loss of financial incentives
- Utility deregulation

DOE CSP Budget

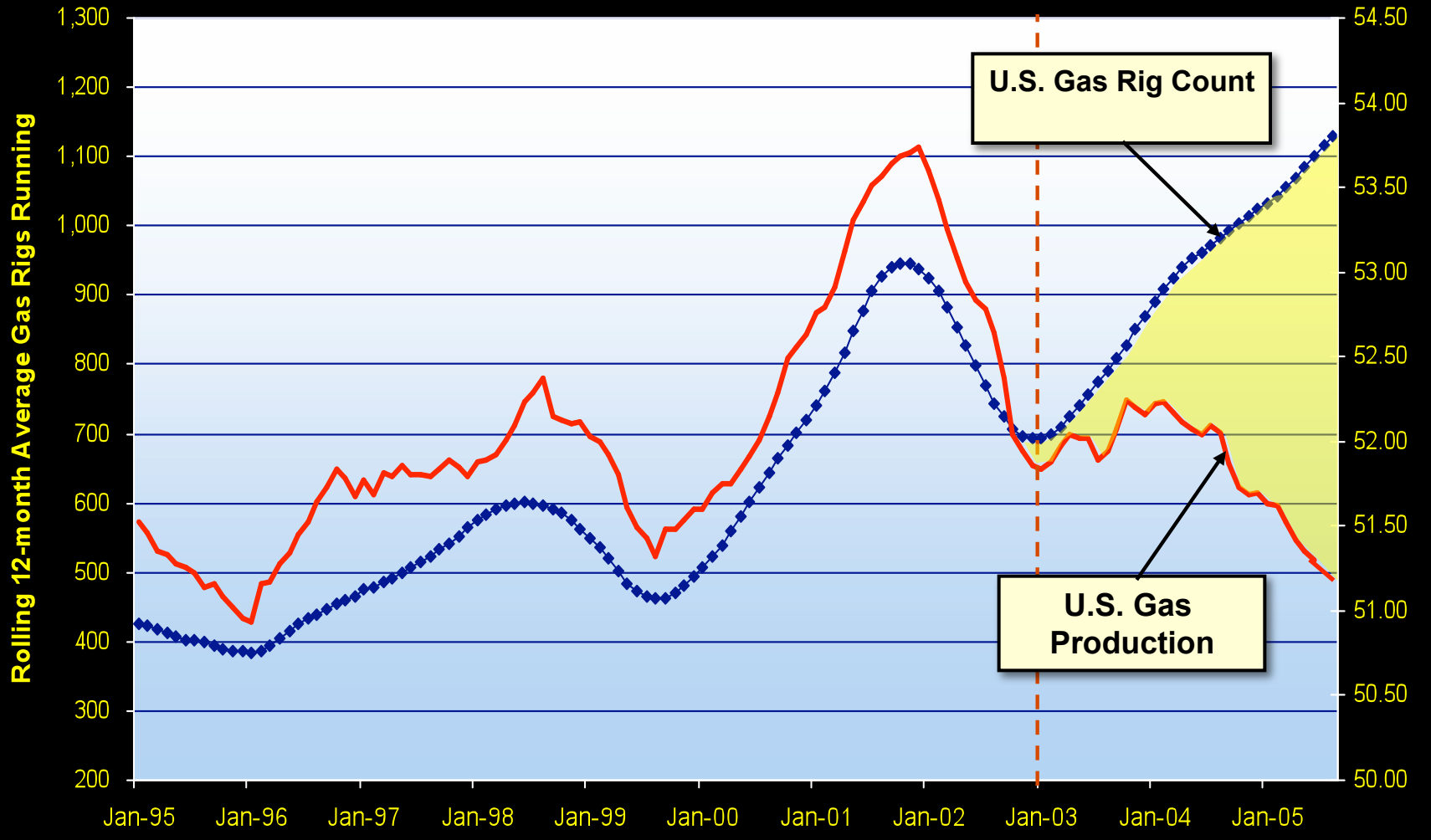


DOE CSP program 2003 - 2006

Why the resurgence?


THE NATION'S CEMETERY
ARLINGTON
NATIONALGEOGRAPHIC.COM/MAGAZINE
JUNE 2009
NATIONAL GEOGRAPHIC
THE BIG THAW
Ice on the Run, Seas on the Rise
THE MAN WHO NAMED PLANTS
CHINA'S BOOMTOWNS

More and More U.S. Gas Wells Producing Less and Less

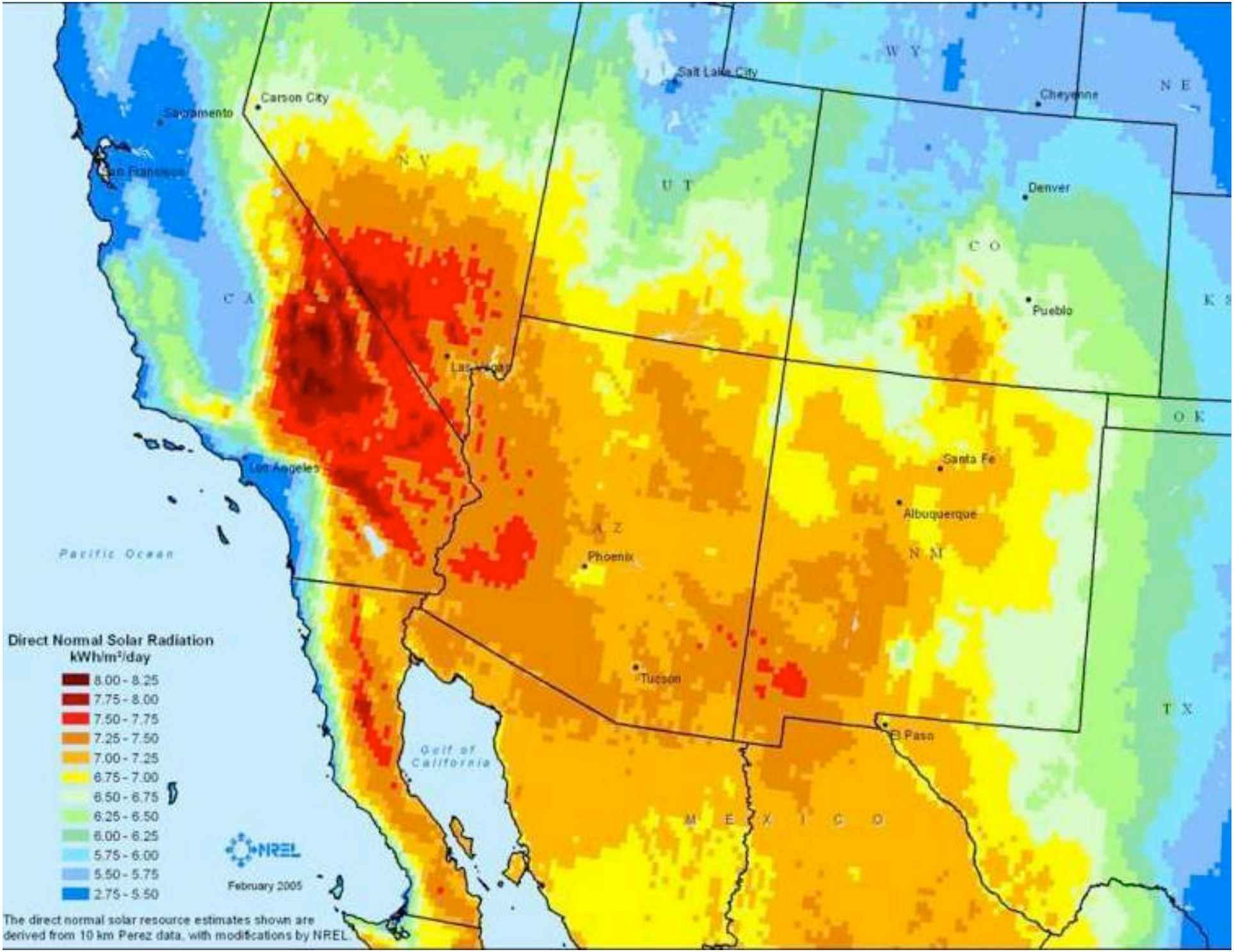


Source: Baker Hughes, EIA/DOE (2004 and 2005 production volumes are EIA estimates)

World Renewable Resource Potential (TW)

Hydroelectric	2
Wind	4
Ocean	5
Biomass	7
Geothermal	12
Solar	600

Source: Marty Hoffert, Nate Lewis

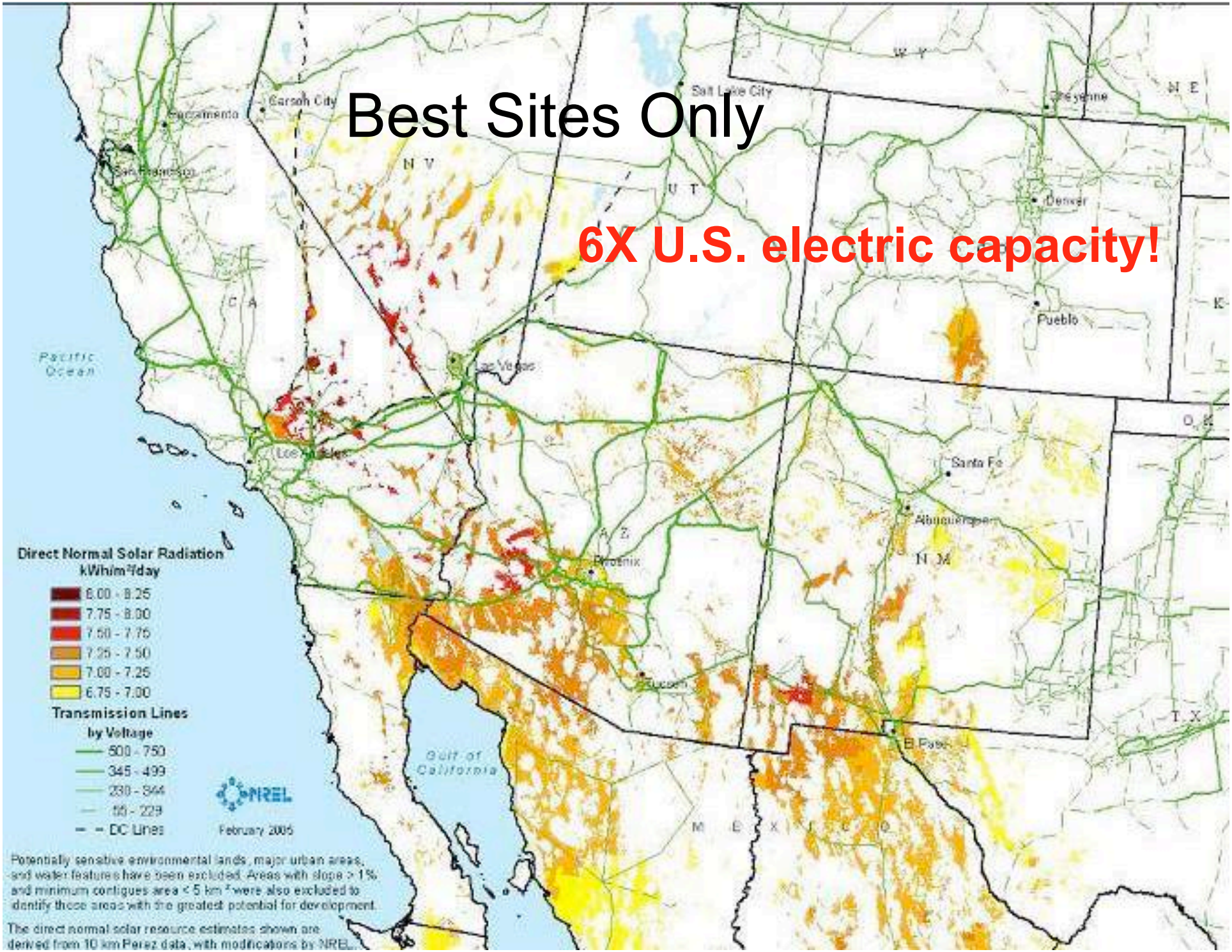

Direct Normal Solar Radiation
kWh/m²/day
8.00 - 8.25
7.75 - 8.00
7.50 - 7.75
7.25 - 7.50
7.00 - 7.25
6.75 - 7.00
6.50 - 6.75
6.25 - 6.50
6.00 - 6.25
5.75 - 6.00
5.50 - 5.75
2.75 - 5.50
NREL
February 2005
The direct normal solar resource estimates shown are derived from 10 km Perez data, with modifications by NREL
Pacific Ocean
Gulf of California
MEXICO
Sacramento
Carson City
Salt Lake City
Cheyenne
Denver
Pueblo
Las Vegas
Los Angeles
Phoenix
Santa Fe
Albuquerque
Tucson
El Paso
NV
UT
WY
NE
CO
CA
AZ
NM
TX
OK

Exclude:

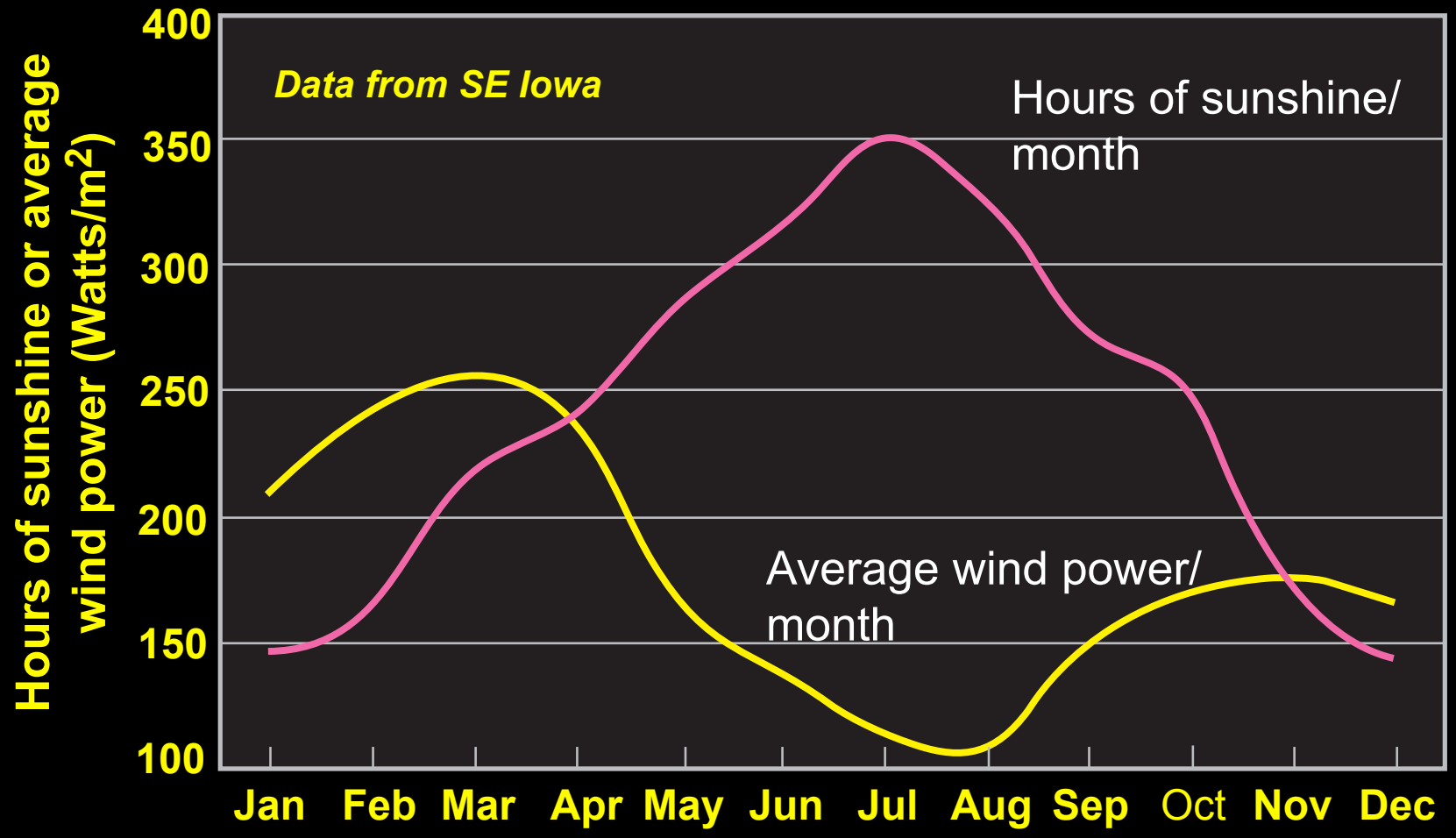
- Used and sensitive land

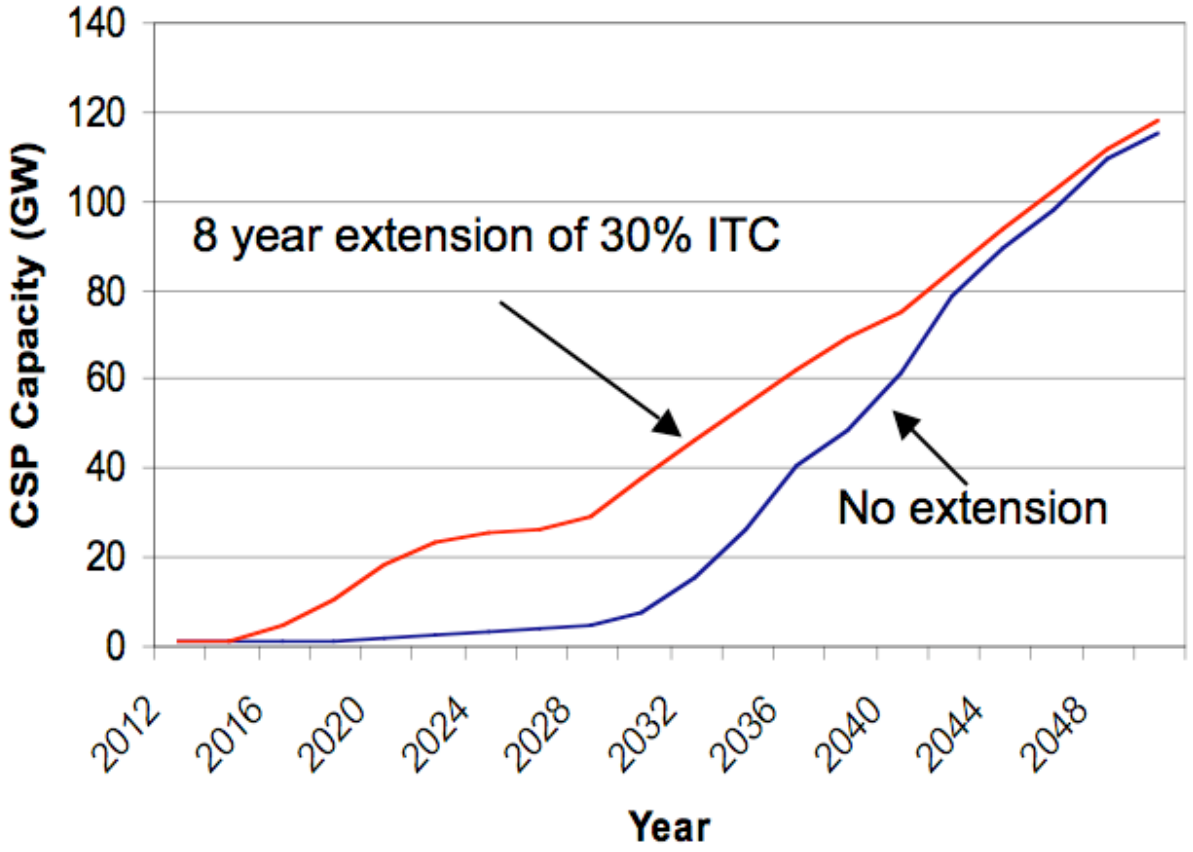
- Solar < 6.75 kWh/m^2 per day

- Ground slope > 1%


Best Sites Only
6X U.S. electric capacity!
Direct Normal Solar Radiation
kWh/m²/day
8.00 - 8.25
7.75 - 8.00
7.50 - 7.75
7.25 - 7.50
7.00 - 7.25
6.75 - 7.00
Transmission Lines
by Voltage
500 - 750
345 - 499
230 - 344
69 - 229
DC Lines
NREL
February 2005
Potentially sensitive environmental lands, major urban areas, and water features have been excluded. Areas with slope > 1% and minimum contigues area < 5 km² were also excluded to identify those areas with the greatest potential for development.
The direct normal solar resource estimates shown are derived from 10 km Perez data, with modifications by NREL.
Pacific Ocean
Gulf of California
Salt Lake City
Carson City
Sacramento
San Francisco
Las Vegas
Los Angeles
Phoenix
Tucson
Denver
Pueblo
Santa Fe
Albuquerque
El Paso
N V
U T
C A
A Z
N M
C O
T X
M E X I C O

Solar and Wind Resources Are Often Complementary




CSP Capacity (GW)
140
120
100
80
60
40
20
0
8 year extension of 30% ITC
No extension
2012
2016
2020
2024
2028
2032
2036
2040
2044
2048
Year

State	RPS Requirement
Arizona	15% by 2025
California	20% by 2010
Colorado	20% by 2020, 4% Solar
Nevada	20% by 2015, 5% Solar
New Mexico	20% by 2015
Texas	5,880MW (~4.2%) by 2015

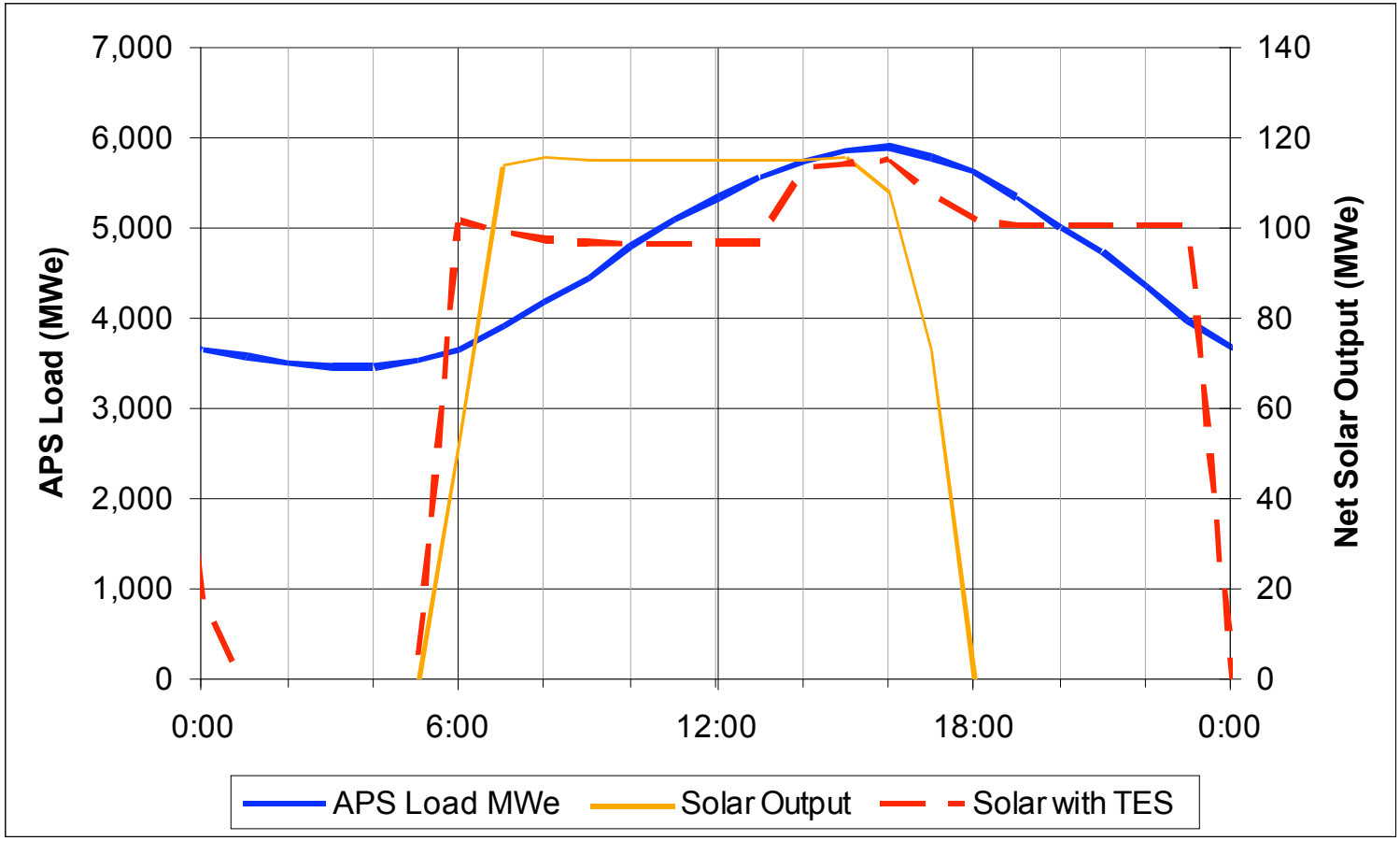
2006 1-MW Saguaro Parabolic Trough Plant

New 64 MWe Acciona Solar Parabolic Trough Plant

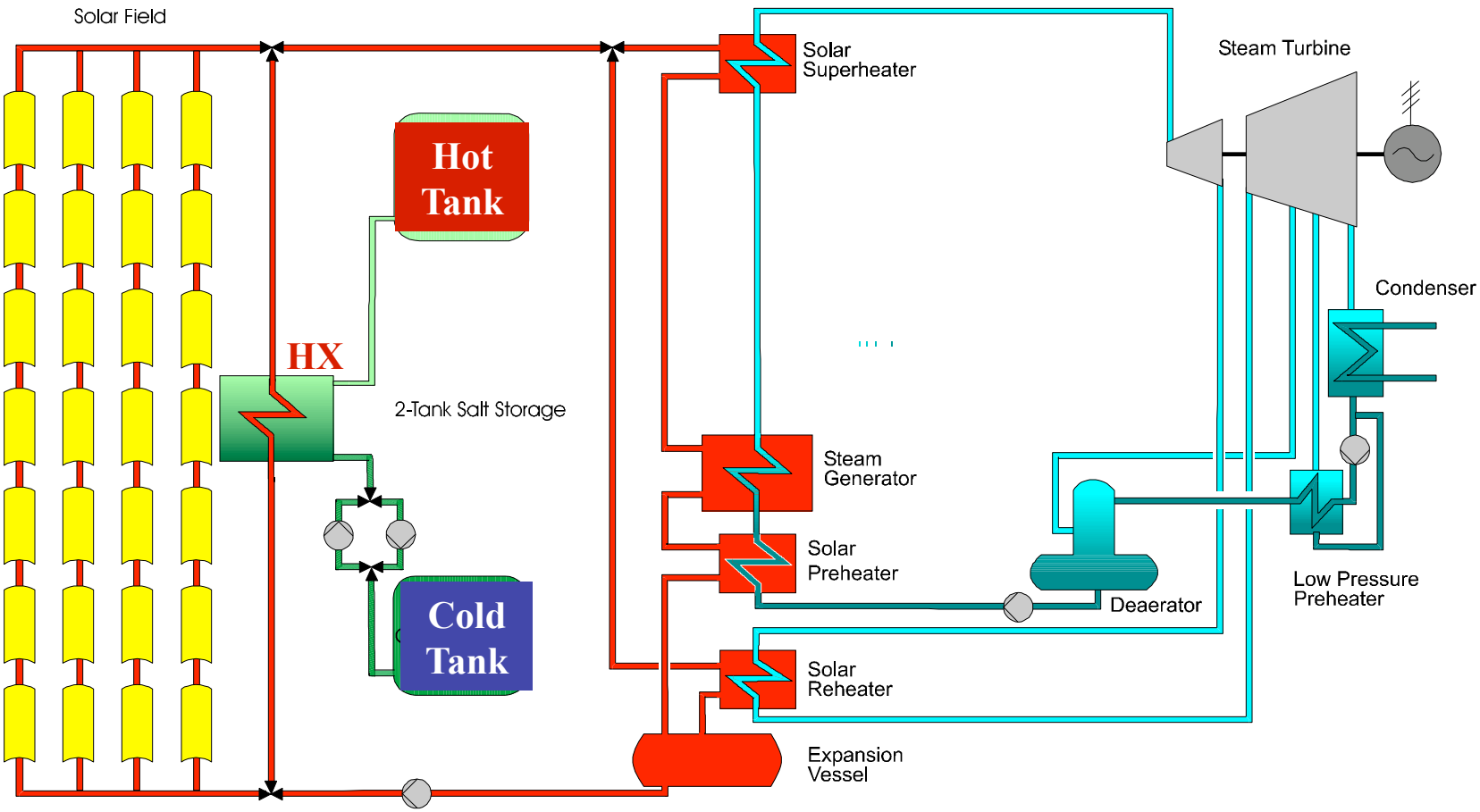
but the BIG ATTRACTION:

STORAGE!

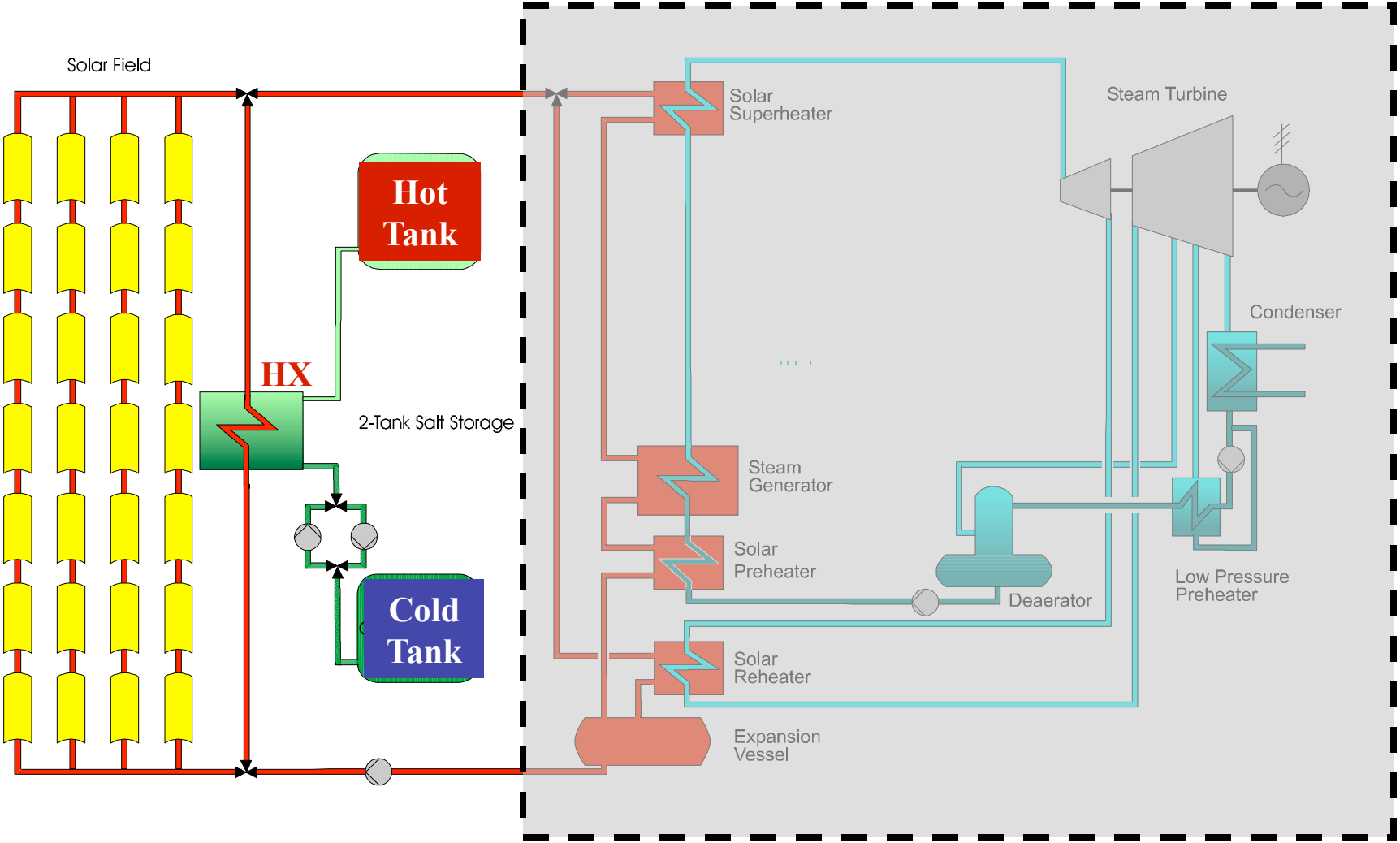
Parabolic Trough Output Profile Summer Day



CSP Power Plant with Thermal Storage

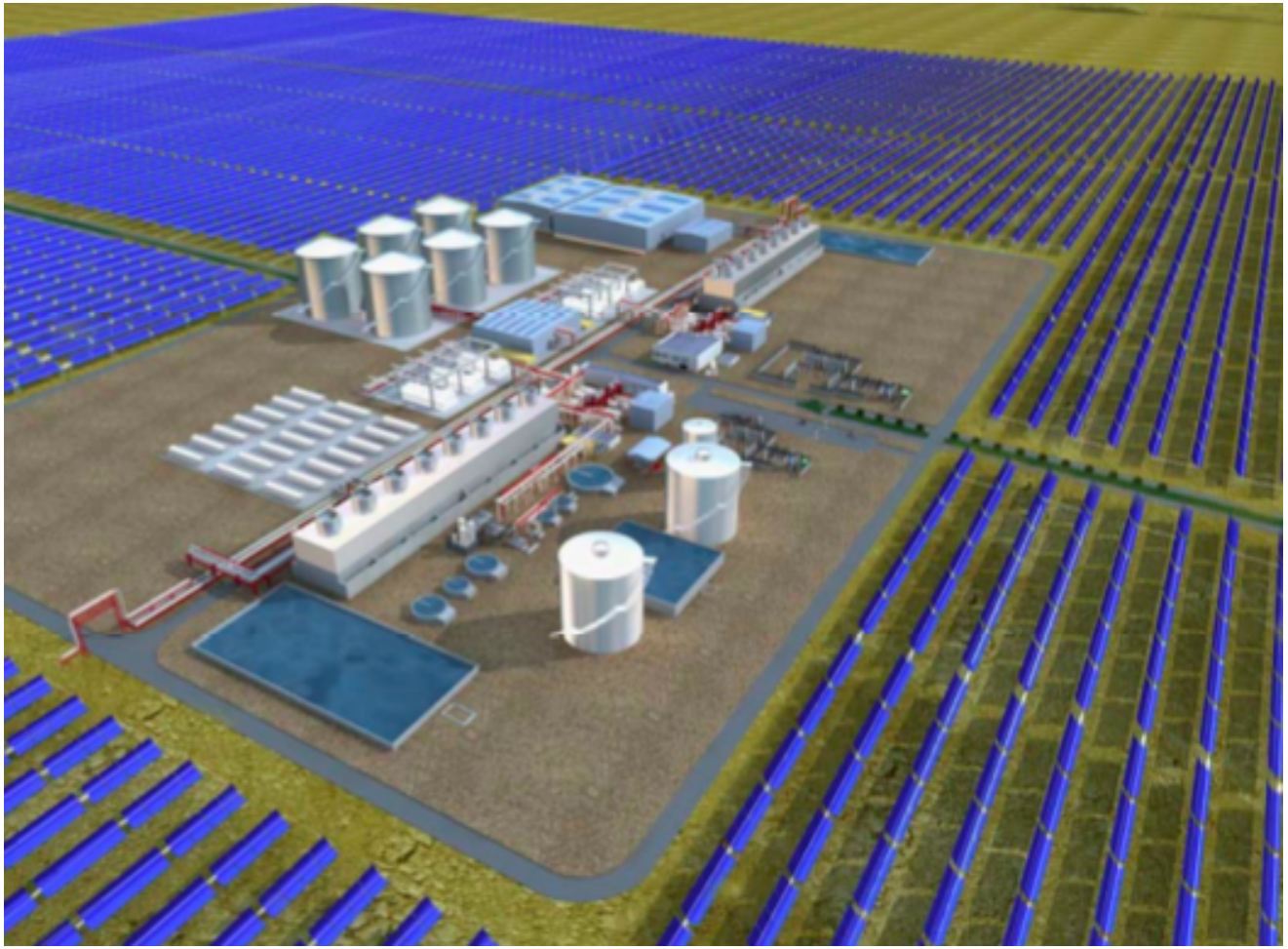


CSP Power Plant with Thermal Storage



50 MW AndaSol-1 Parabolic Trough Plant w/ 7-hr Storage
Andalucia, Spain

Planned 280 MW Solana Plant with 6 hrs Storage



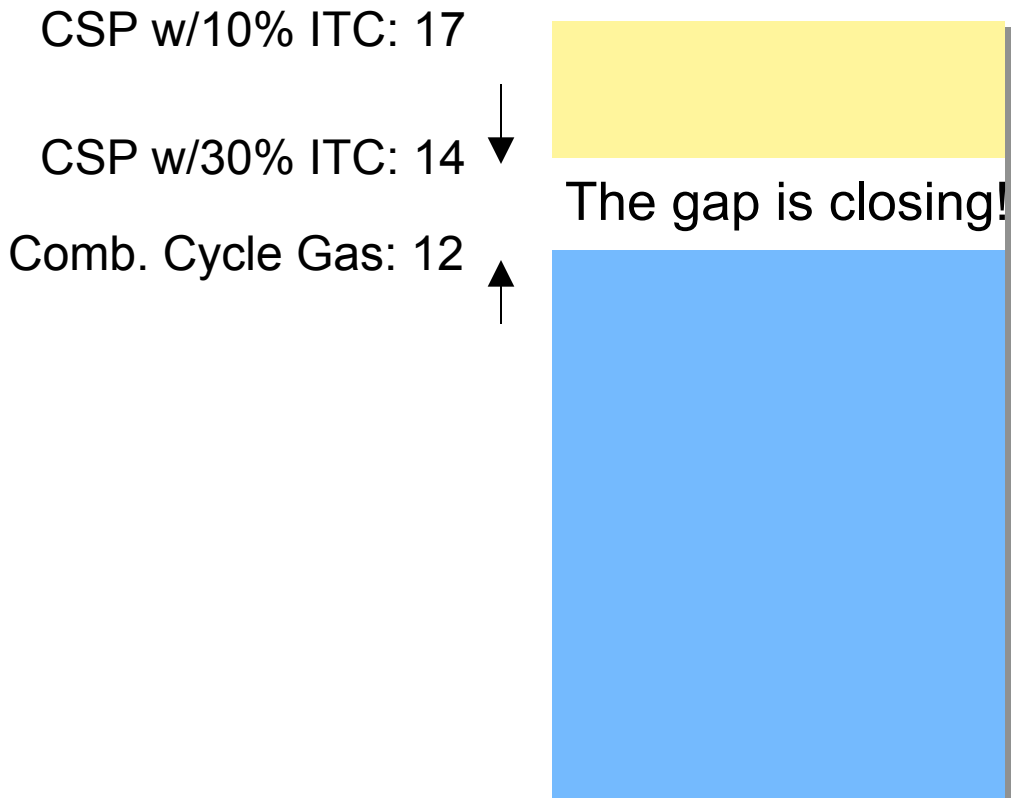
Artist Rendition

1500 construction jobs over two years

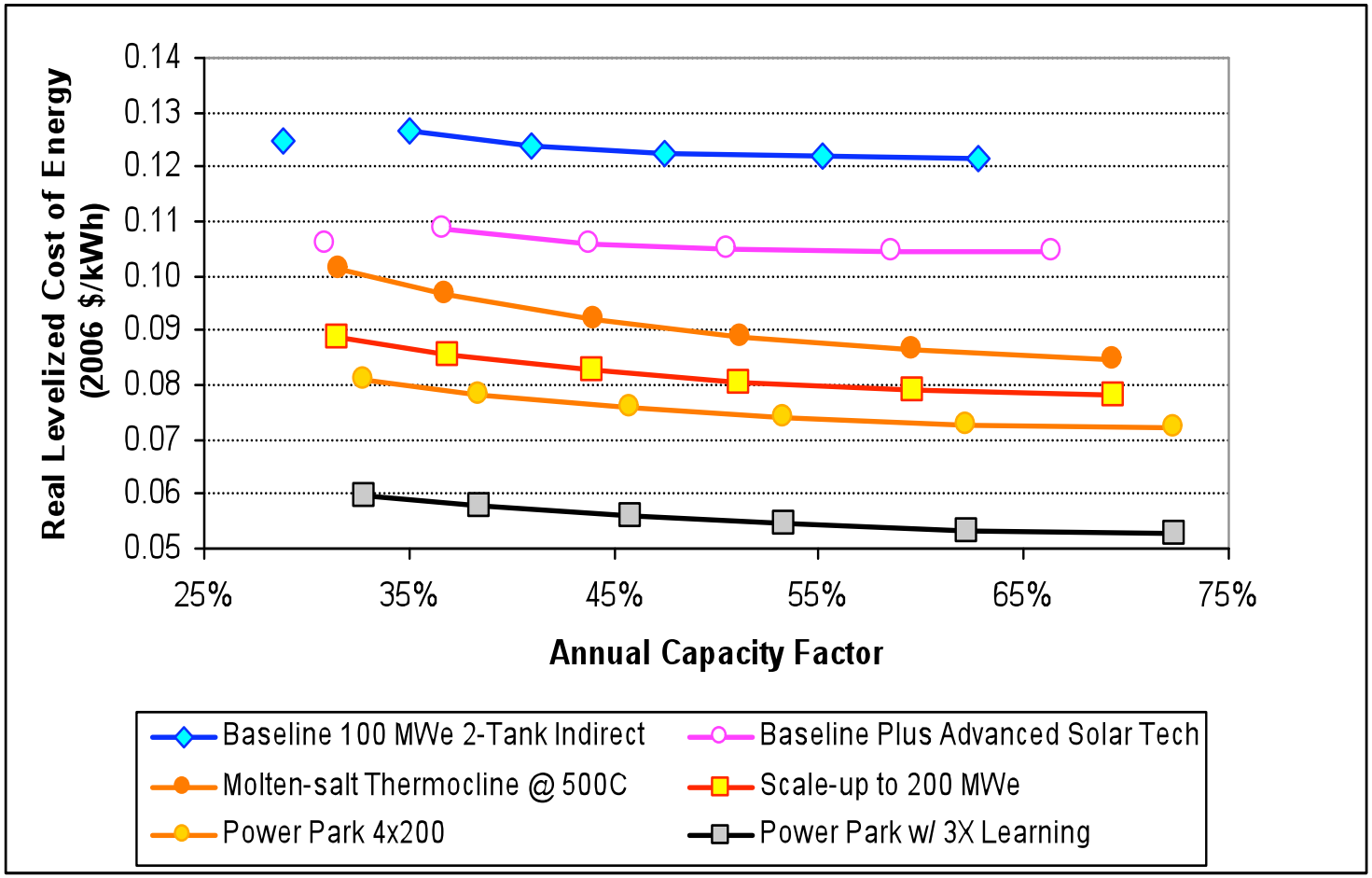
85 permanent jobs

APS
Renewable Energy

Cost of CSP (¢/kWh)

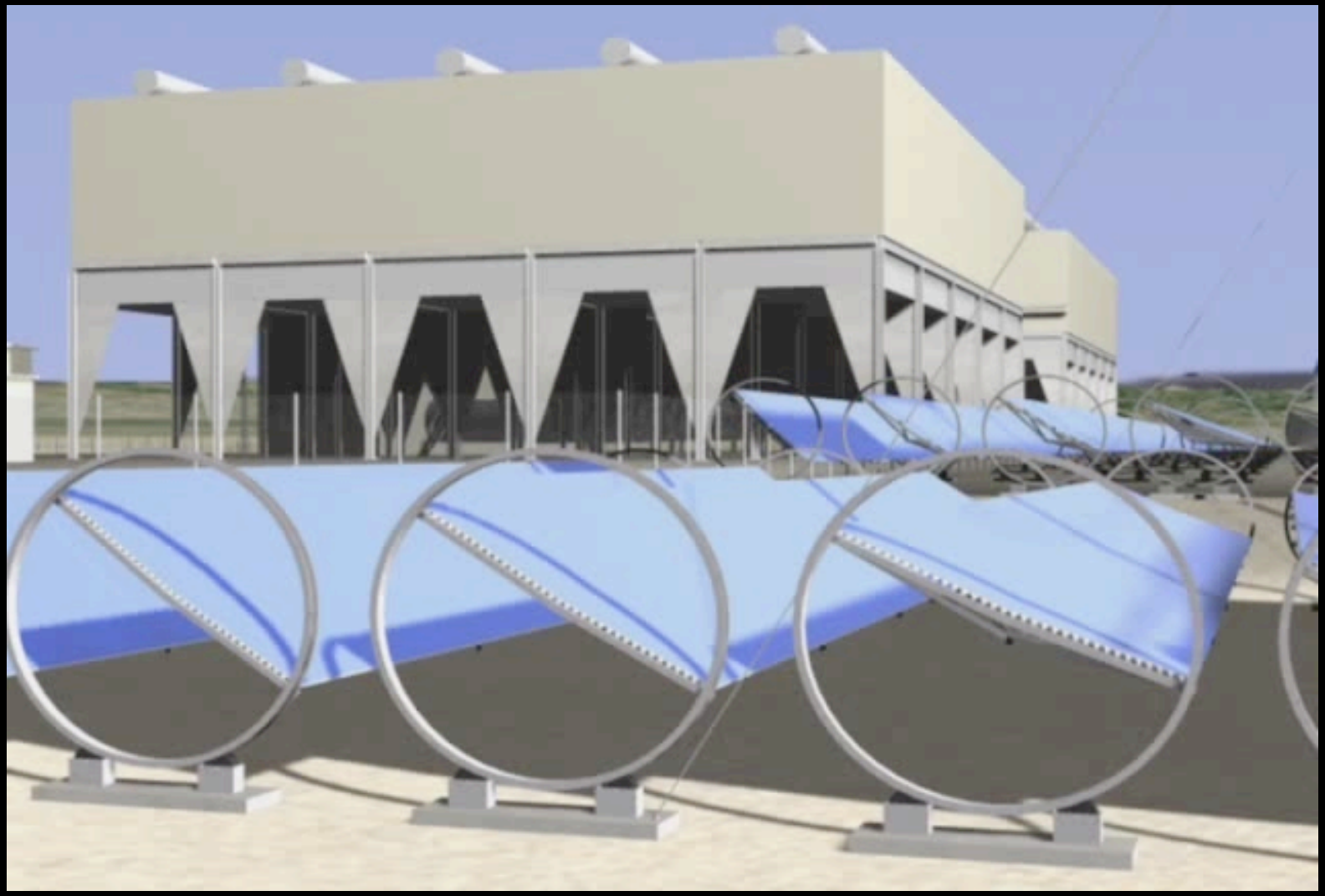


Parabolic Trough
Potential Cost Reductions



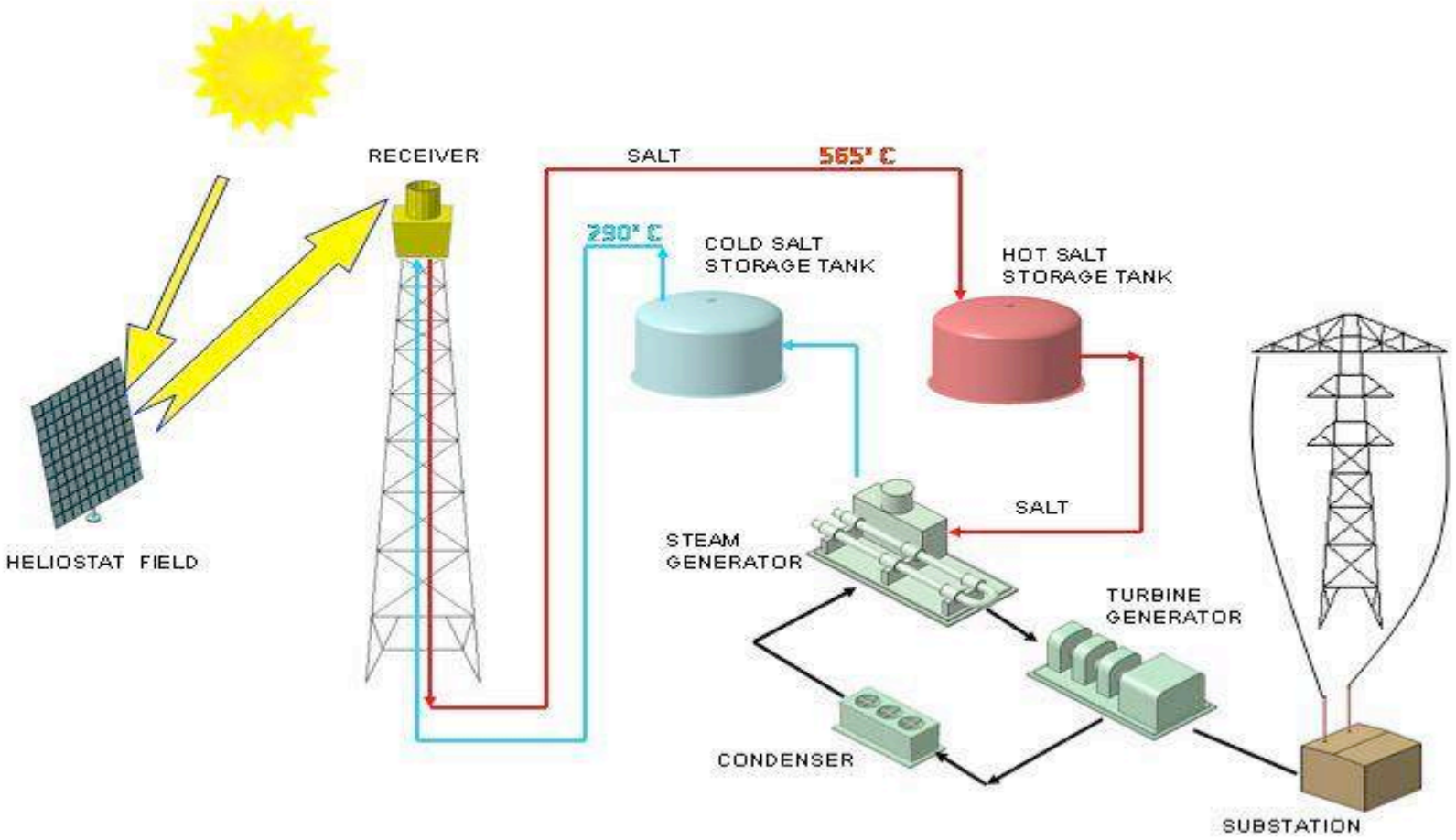
Linear Fresnel

Planned 177 MW Air-Cooled Plant for PG&E



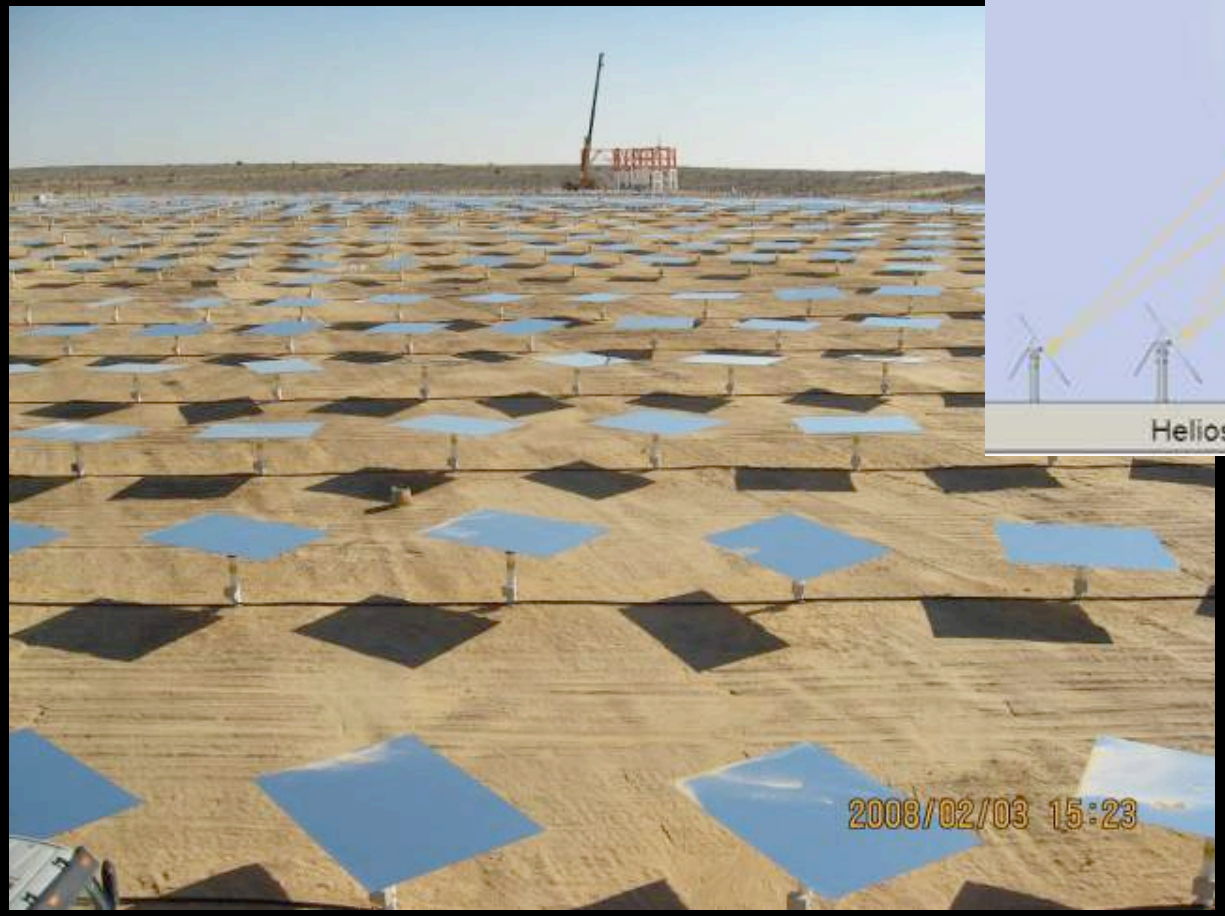
Artist Rendition

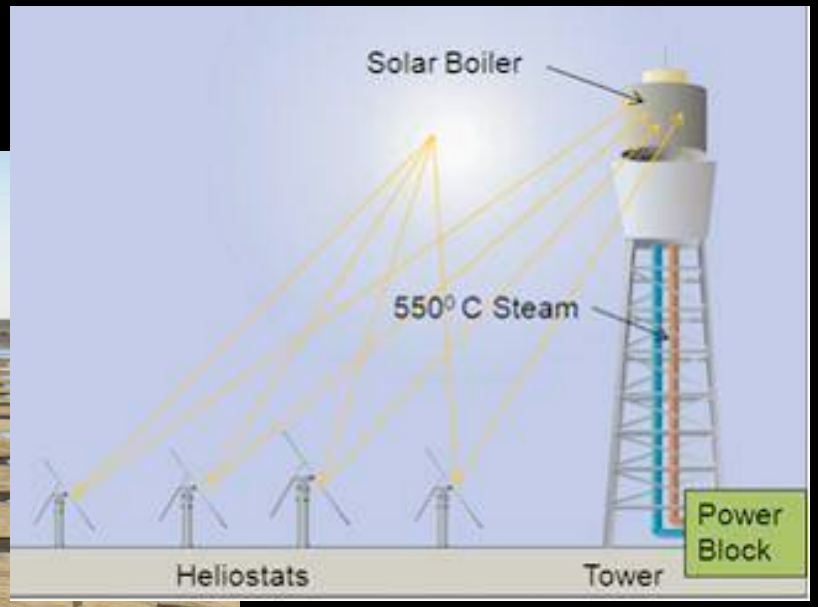
Power Tower or Central Receiver with Thermal Storage



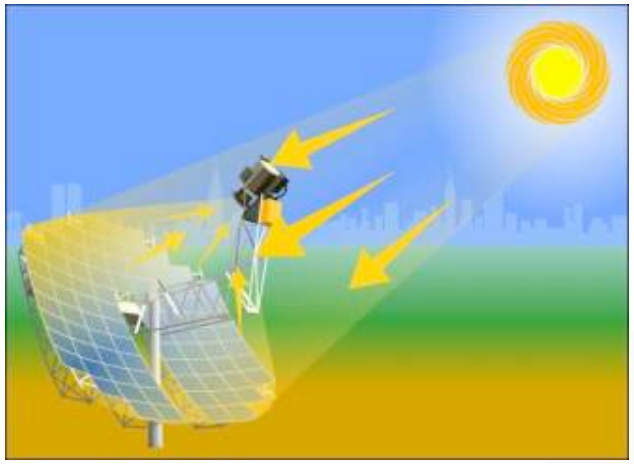
Abengoa PS10 and PS 20
Seville, Spain

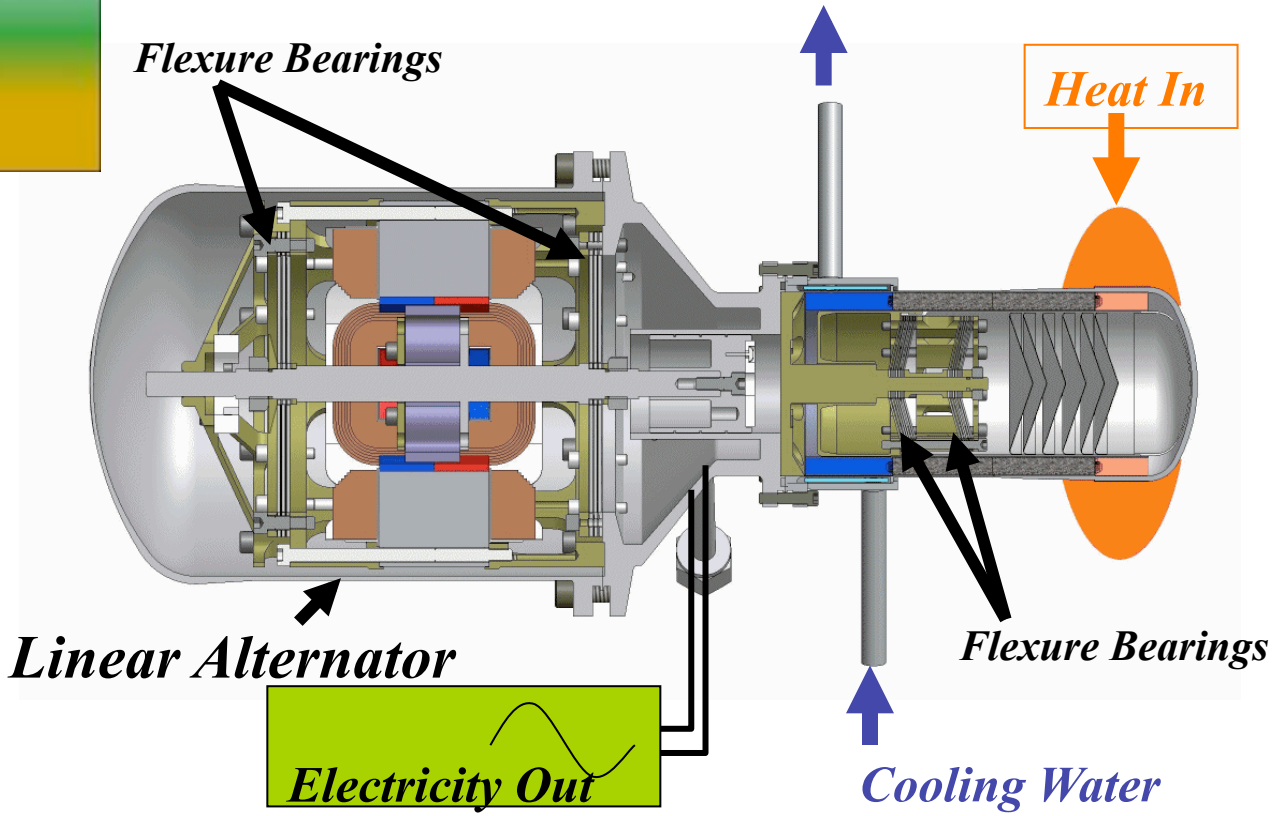
BrightSource Distributed Power Tower





Dish/Stirling System





Six Dish Prototypes at Sandia-Albuquerque

the future of csp

Contracts for over 4,500 MW of U.S. Projects

1,365 MW

1,750 MW

1,211 MW

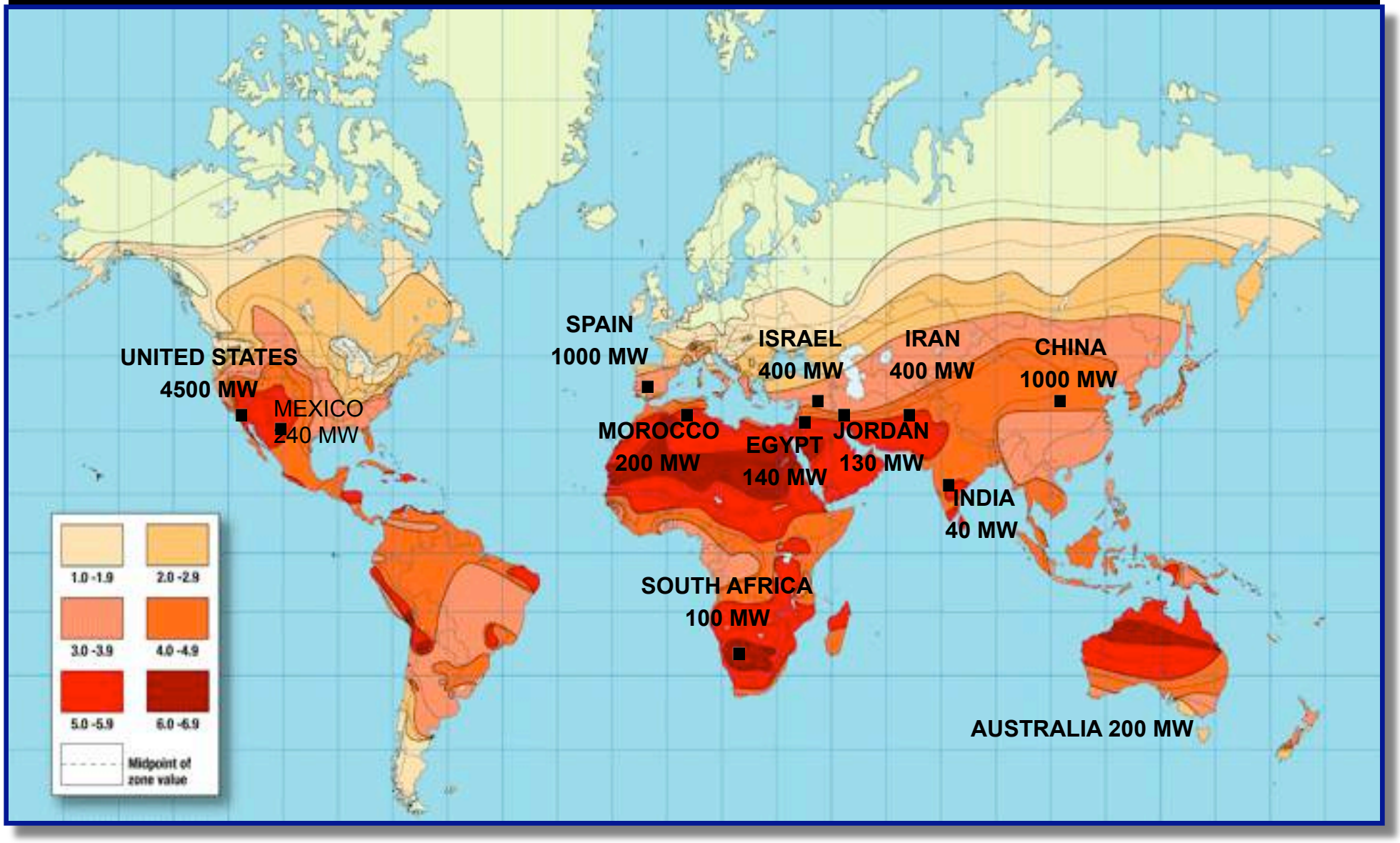
177 MW

Solar Applications for BLM-Managed Land

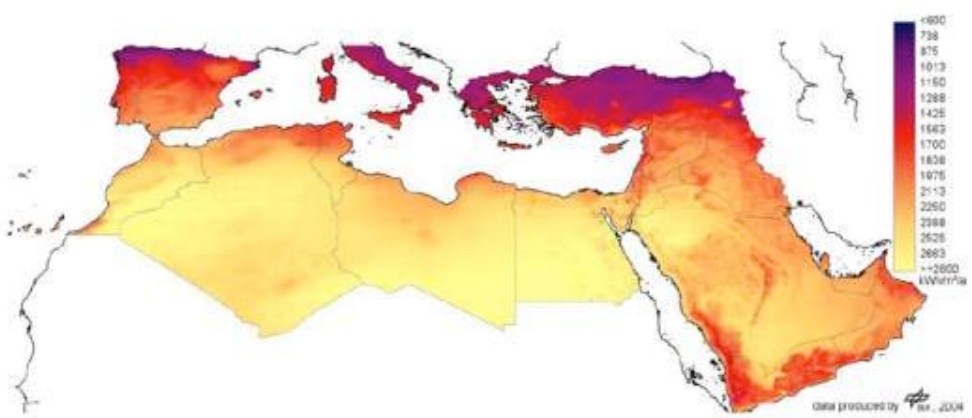
- Over 50 different companies have filed 97,000 MW of applications
- 40% trough; 20% tower; 20% PV; 20% other

State	Cases	Acres	MWs	Technology		
				CSP	PV	Unknown
AZ	38	771,060	27,258	34	4	0
CA	72	639,172	48,181	42	27	3
CO	1	2,100	150	0	1	0
NM	7	61,919	3,070	6	1	0
NV	40	299,640	18,920	31	9	0
Totals	**158**	**1,773,891**	**97,597**	**113**	**42**	**3**

Over 7,500 MW Planned Worldwide

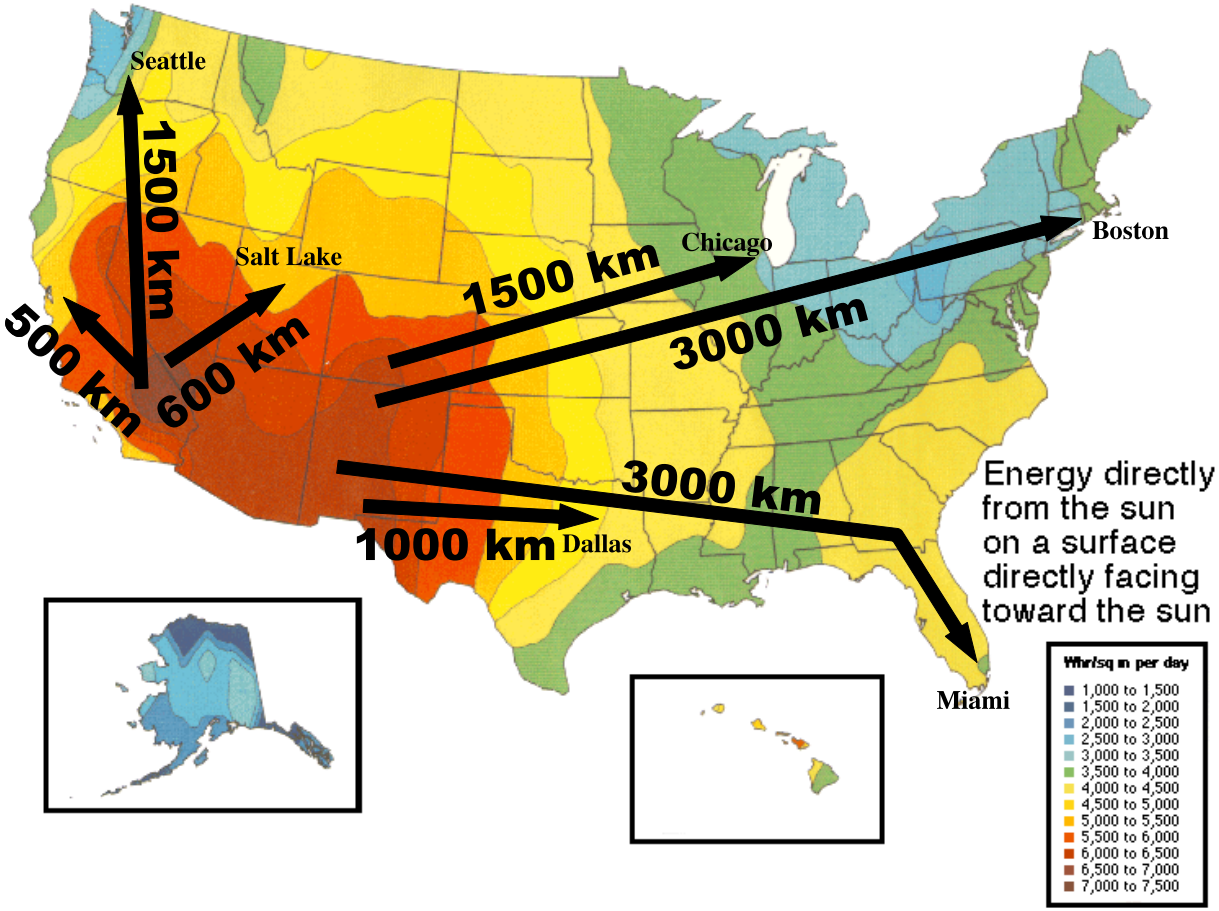


Long Distance Transmission: Europe



"Concentrating Solar Power for the Mediterranean Region," German Aerospace Center (DLR), 2005

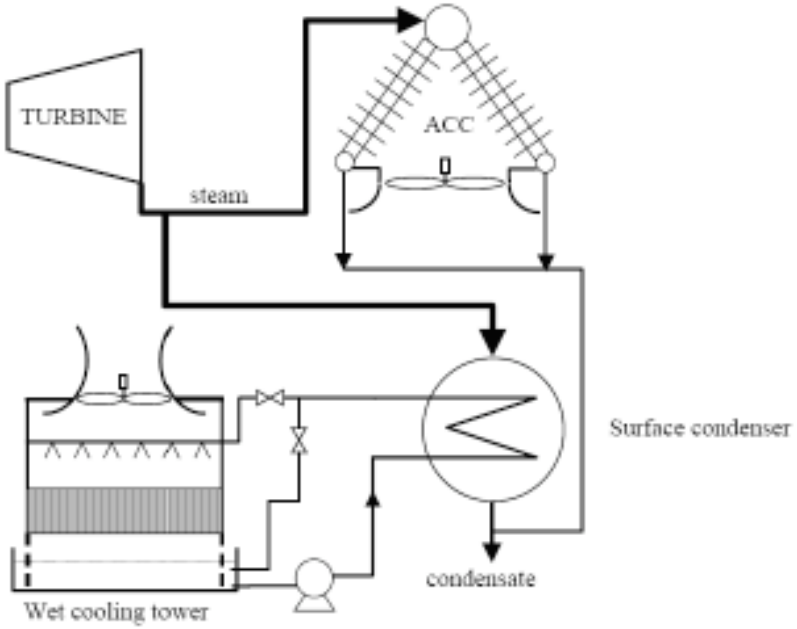
Long Distance Transmission: U.S.

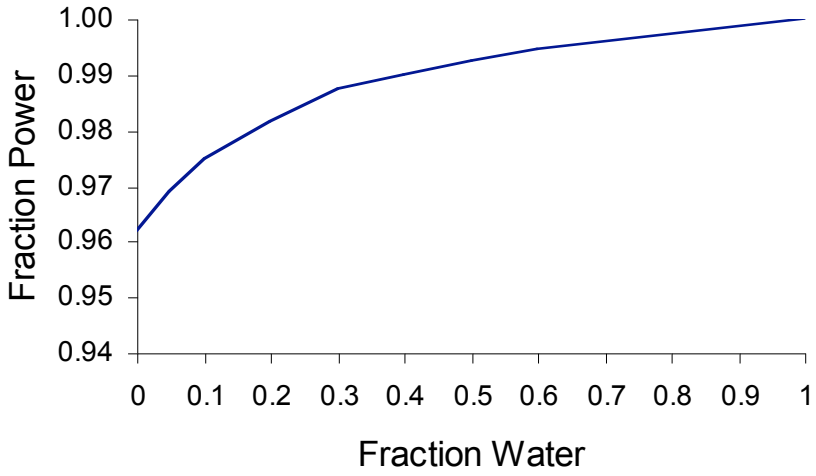


Challenges for CSP

Water Usage

- Hybrid air/water cooling systems can reduce water use 80% with modest performance and cost penalties

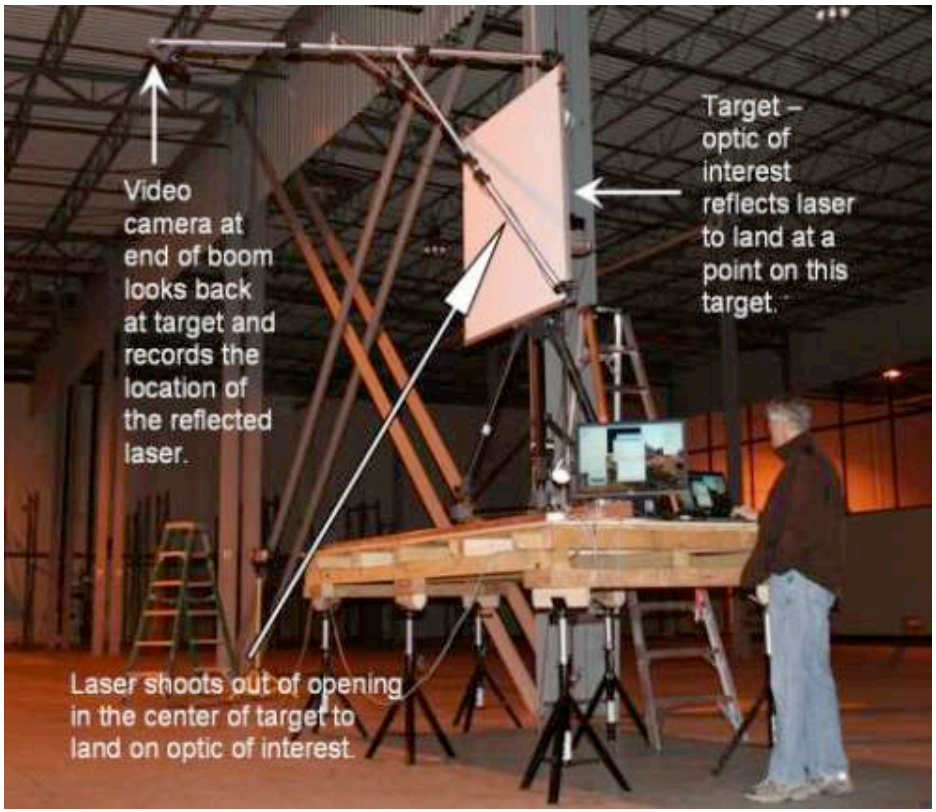




Land Use/Habitat

NREL CSP
R&D Highlights

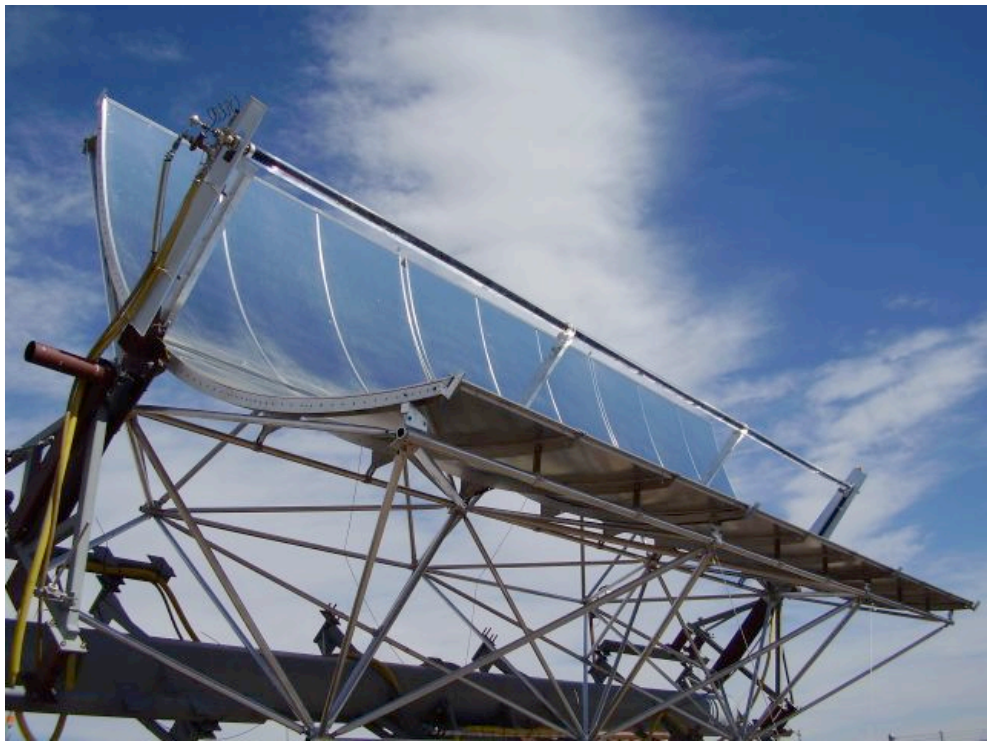
Optical Collector Characterization



Indoor test

Field test

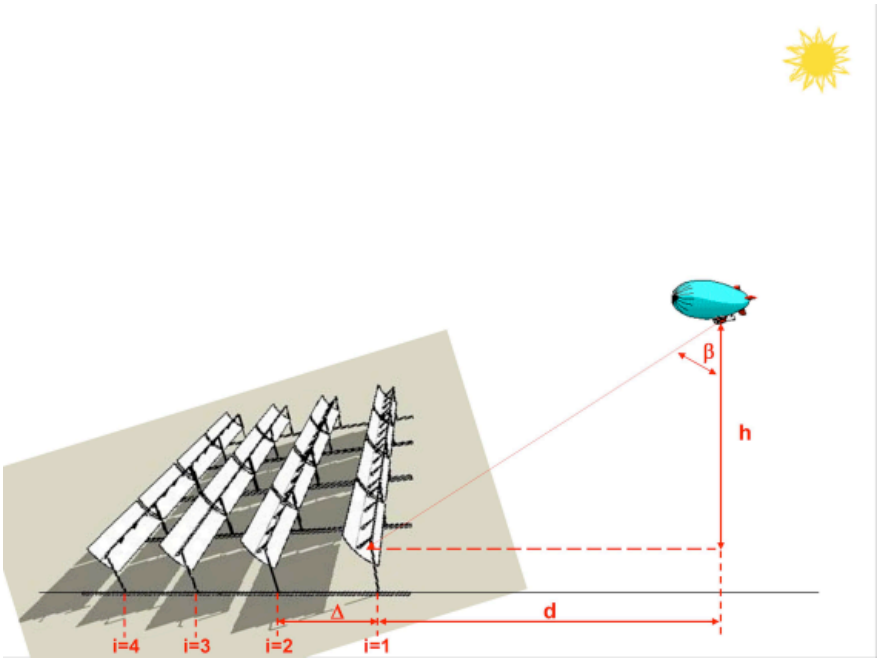
Optical Efficiency Test Loop

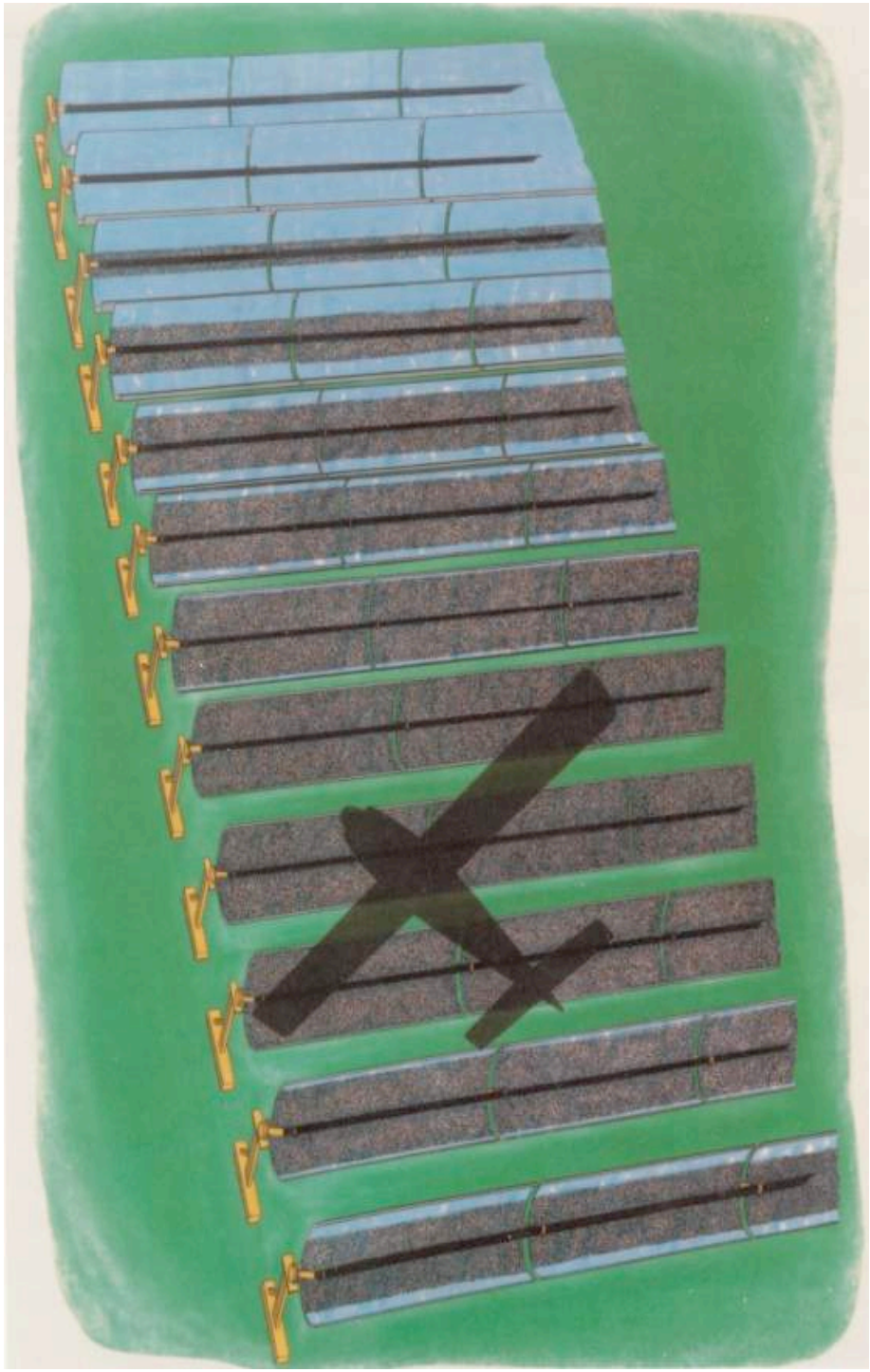


SkyTrough undergoing test

Control room showing tracker and loop controls

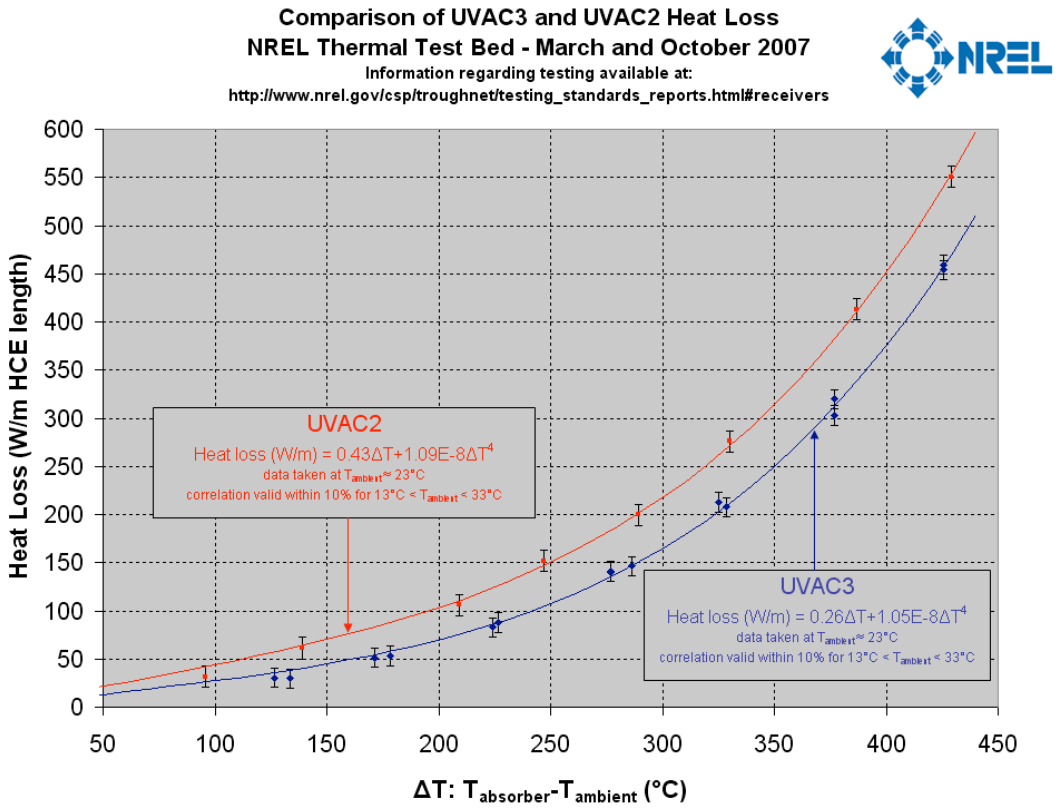
Distant Observer Field Assessment Tool





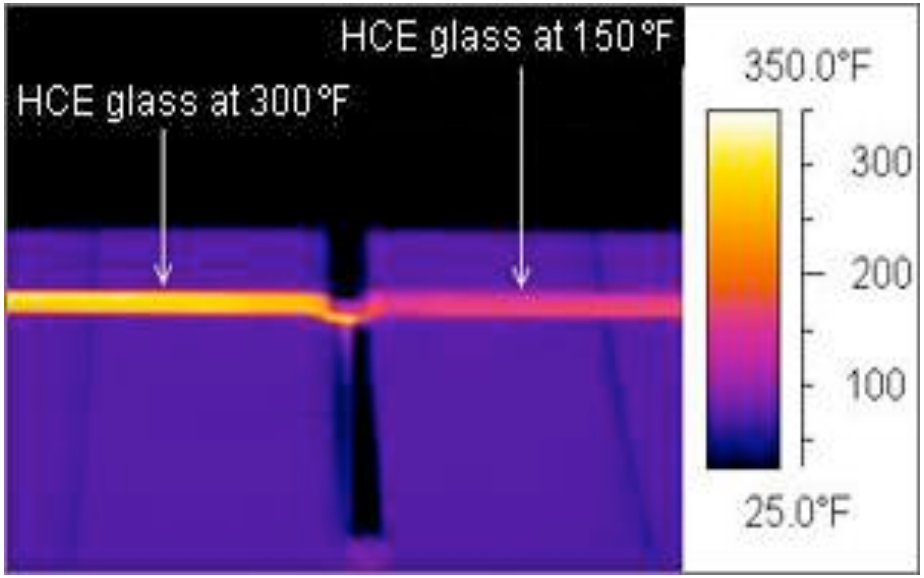
Receiver heat loss: laboratory measurements

Receiver test rig



Receiver heat loss: field surveys

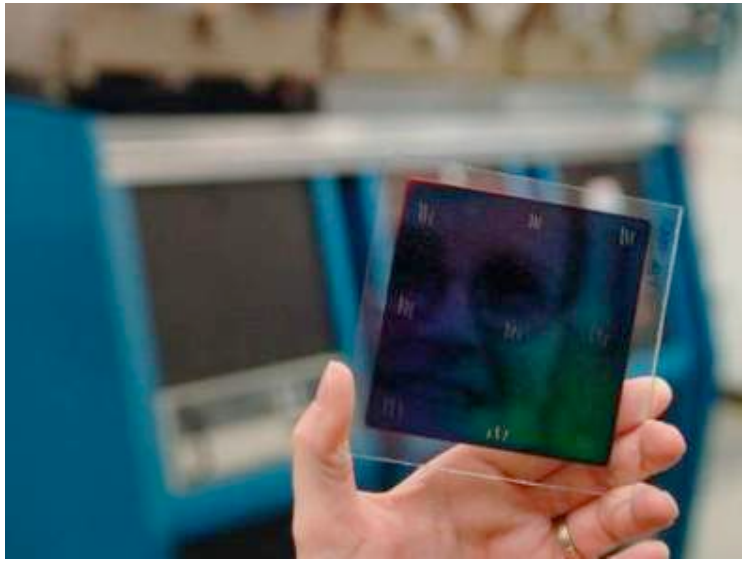
Camera and GPS for exact positioning



Infrared image of hot and cold tubes

Advanced Materials Development

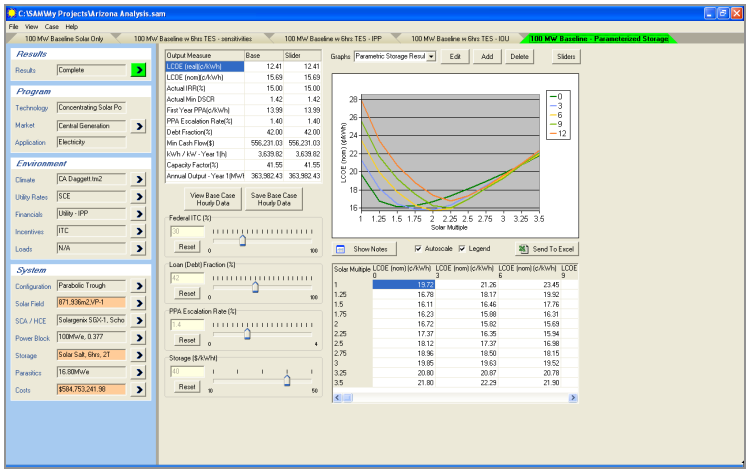
ReflecTech® film



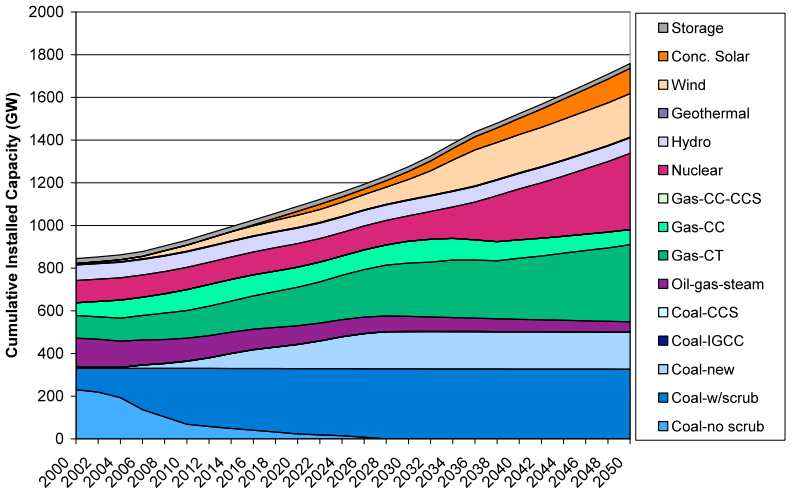
Low-ε receiver coating

Modeling and Analysis Tools

Solar Advisor Model (SAM)

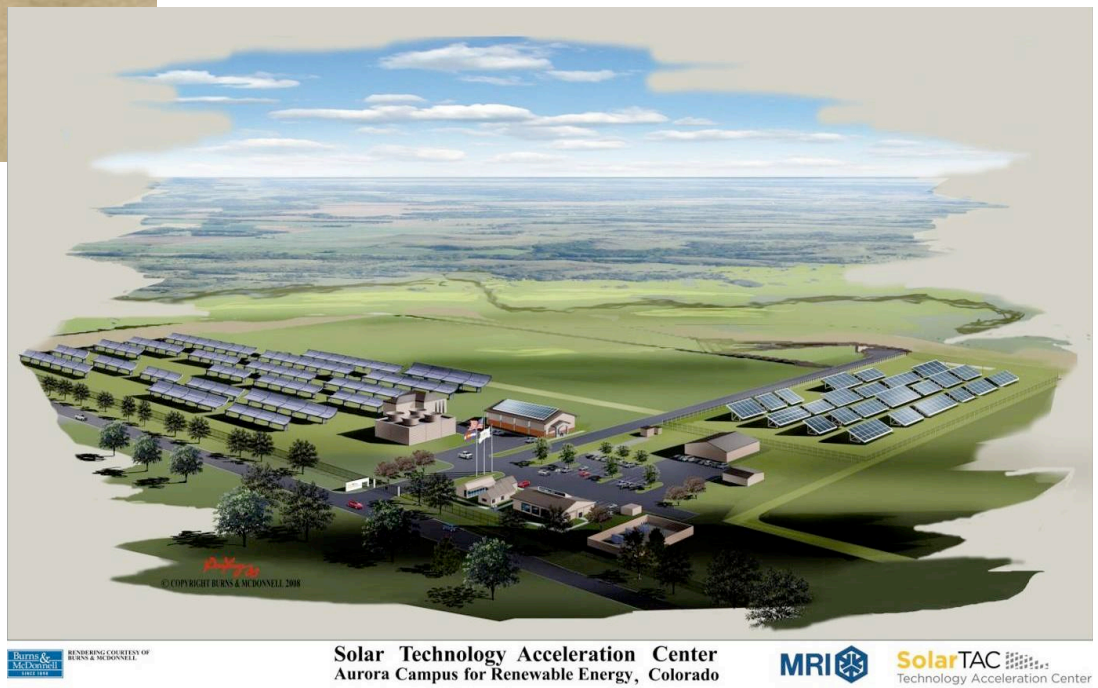


Regional Electricity Deployment System Model (REEDS)



Facilities Under Development/Construction

Energy Systems Integration Facility



Solar Technology Acceleration Center

TACKLING CLIMATE CHANGE:

Concentrating Solar to the Rescue

Why a nearly forgotten solar technology is emerging as a promising weapon in the war on climate change.

By CHUCK KUTSCHER

Chuck Kutscher is a principal engineer and manager of the Thermal Systems Group at the National Renewable Energy Laboratory. He is a past ASES chair and was chair of the SOLAR 2006 conference, which resulted in the ASES report, "Tackling Climate Change in the U.S." (Free download at ases.org/climatechange.) He teaches a course at the University of Colorado entitled "Climate Change Solutions."

The opinions expressed here are solely those of the author.

What comes to mind when you think of solar electricity? If you're like most people, you think of photovoltaic (PV) modules. But another type of solar technology generates electricity in a way that is much like conventional power plants: concentrating solar power, or CSP. As longtime solar advocate Fred Morse puts it (in a takeoff on the old pork industry ads), CSP is "the other white meat."

CSP is simple enough. Mirrors concentrate solar energy, producing the high temperatures needed to efficiently run a thermodynamic heat engine. Because diffuse sunlight can't be focused, CSP plants work best where skies are very clear, like the southwestern United States. A study done for the Western Governors' Association looked at the Southwest and filtered out land that was already utilized or environmentally sensitive, had a ground slope greater than 1 percent and had anything less than the best solar resource (6.75 kilowatt-hour per square meter per day of direct radiation). They concluded that the remaining land could provide six times the current U.S. electric capacity.

CSP isn't new. In the 1980s, the Israeli company Luz constructed nine plants for a total of 354 megawatts (MW) of CSP in the Mojave Desert, and these plants are still operating successfully. They employ tracking parabolic trough reflectors to focus sunlight onto evacuated tube receivers, through which a high-temperature heat-transfer fluid is pumped. The fluid transfers its heat to a boiler, and the steam spins a turbine-generator.

After the last Luz plant was built in 1991, Luz went out of business. The loss of financial incentives, low natural gas prices and utility deregulation all conspired to kill the industry. But in the last three years, CSP has experienced a rebirth. Higher natural gas prices and a 30 percent federal investment tax credit, recently extended for eight years, have made CSP attractive again. Renewable portfolio standards in 28 states have put pressure on utilities to produce or buy electricity from renewable energy. And utilities understand big steam-generating power plants.

In 2006, Solargenix (now Acciona, acciona.es) installed America's first new parabolic trough power plant in 15 years. Although only 1 MW in size, the Saguaro plant outside Tucson provided the field experience needed to build the 64-MW Nevada Solar One plant outside Las Vegas only a year later. The Saguaro plant also gave Arizona Public Service (APS) experience integrating CSP into their grid. When APS decided recently to order a new power plant to service Phoenix's growing population, they compared wind turbines, photovoltaics and CSP to a new combined-cycle natural gas plant. They chose CSP because it offers one key advantage: storage. CSP plants generate heat, and storing heat is cheaper and more efficient than storing electricity.

The 250-MW (net) Solana plant being built by Abengoa (abengoa.com) for APS will incorporate six hours of thermal storage. A parabolic trough collector field will be oversized so that, when the sun is shining, it will not only generate electricity to send out to the grid but will also heat tanks of molten salt. After the sun sets, the heat from the molten salt will be transferred to the same fluid that goes through the collectors, which can then continue to boil water for the steam turbines. Thus the utility can meet high demand through the evening hours when people get home from work. Solana is expected to create 1,500 construction jobs and 85 permanent jobs.

While the Solana plant will employ six hours of storage, and new plants in Spain are using seven hours, analysts at the National Renewable Energy Laboratory (NREL) are looking into 12 hours or more of storage, allowing CSP to compete in the base load power market, now dominated by coal, the worst carbon emitter. Of course, carbon price legislation will be needed to allow CSP to compete economically against coal.

It is estimated that electricity from Solana will cost about 14 – 15 cents per kilowatt-hour, after the tax credit, compared to about 12 cents per kilowatt-hour for a new combined-cycle plant. But the solar plant will eliminate the risk associated with potential future price hikes in natural gas. While further cost reductions are needed, CSP technology is improving. The newest receiver tubes being tested at NREL lose significantly less heat than those at Nevada Solar One. New polymer reflector materials have the potential to replace heavy glass mirrors, thus reducing the overall collector cost. One need only look

www.solartoday.org

Climate Change: Here Today, Gone Tomorrow (2050)

A pathway to U.S. carbon emission reductions

Timothy Stovall, Kathleen Stynes, Philip Taylor

Climate Change Happening: Caused by People

Rapid commercial, industrial and agricultural expansion has released huge amounts of greenhouse gases into the atmosphere causing global warming. Figure 1 shows that CO_2 concentrations are higher than anytime during the last 450,000 years and that temperature changes are tightly coupled to the concentrations of greenhouse gases. Figure 2 shows that observations of recent global temperature rise are attributable to anthropogenic sources of emission.

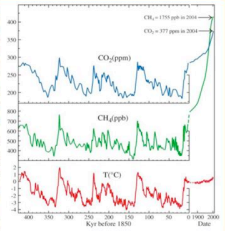


Figure 1: Long- and short-term global CO_2 concentration and temperature (GISS).

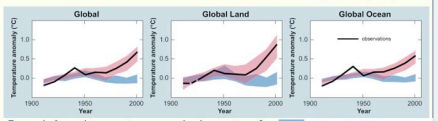


Figure 1: Annual temperature anomaly observations fit with fit including and excluding anthropogenic forcings.

Stabilization at 450 ppm CO_2

1) Limit warming to 2°C to avoid most "tipping points"

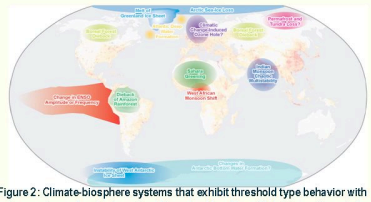


Figure 2: Climate-biosphere systems that exhibit threshold type behavior with warming. Arctic Sea-Ice Loss and Greenland Ice Sheet Melt respond to < 2°C.

2) Political Feasibility: 450 target fits emission reduction pathway in 10/10 110th Congressional cap-and-trade proposals

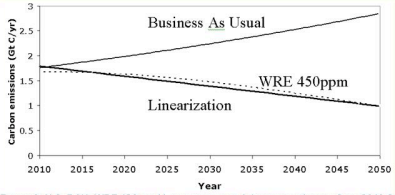


Figure 3: U.S. BAU, WRE 450, and Linearization stabilization pathways from 2010-2050

The Way Forward

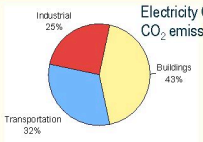


Figure 4: U.S. CO_2 emissions by sector

Electricity Generation accounts for 40% of U.S. CO_2 emissions (distributed across all sectors)

Emissions to Target

- •Transportation Efficiency
- •Building Efficiency
- •Electricity Generation

Carbon Emission Displacement Wedges

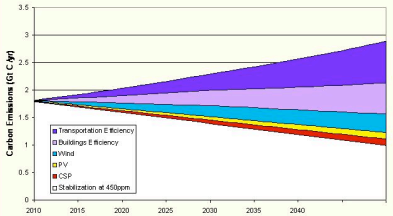


Figure 5: Stabilization wedges accounting for emission reductions by each sector.

Grid Integration

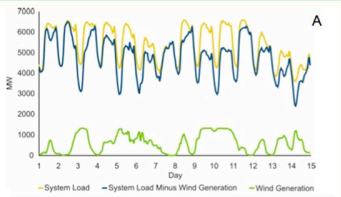


Figure 6: Intermittency in wind causes misalignment with load

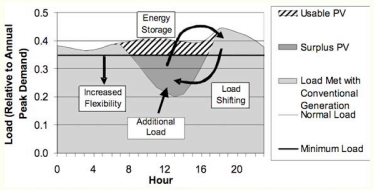


Figure 7: Example of load shifting to accommodate PV penetration

Transmission

- New transmission for 550GW of new capacity costs $110 billion
- Private investment $8 billion in 2007, $8.4 billion in 2009
- With continued private investment, required transmission complete by 2027

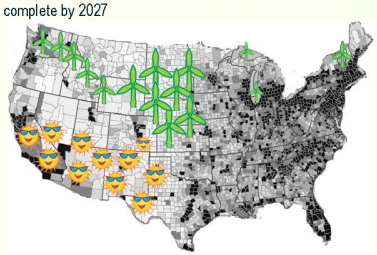


Figure 8: Population density and renewable resources in the U.S.

Transportation Efficiency

Corporate Average Fuel Economy (CAFE) Standards

- Increase fleet average 1mpg/year
- Historic precedent 18mpg(1978) to 28.5 mpg (1988)

Reduce national Vehicle Miles Traveled (VMT)

- Increased gas tax and improved public transportation
- Historic precedent: 3% reduction from 2007 to 2008

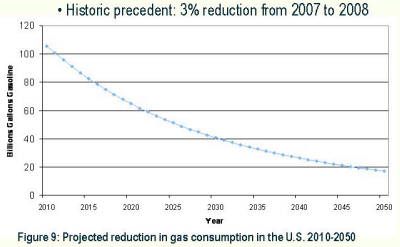


Figure 9: Projected reduction in gas consumption in the U.S. 2010-2050

Building Efficiency

Design to the neutral cost point (60% energy savings) in all new and renovated buildings.
By 2050 75% of building stock will be either new or renovated

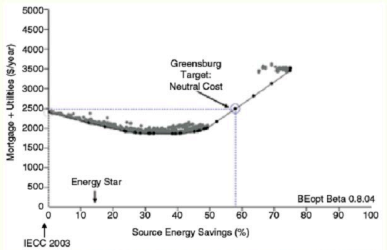


Figure 10: Energy savings by adding energy efficiency into building design (Judkoff. MRS Bulletin Vol 33. April 2008.)

Marketing

- Only 50% of public transportation agencies have a marketing department (most are understaffed, underfunded)
- •We Energies: Reduced 55MW peak load by marketing.
- •Green jobs added 8.5 million jobs and generate $970 billion in revenue
- •Marketing has potential to drastically improve energy efficiency support and progress.

Fuel Reduction and Energy Efficiency Standards

FREEdom† standards to replace CAFE standards

- •Establish fixed annual increases in standards
- •Allow trading between auto manufacturers
- •Remove car/light truck categories
- •Apply standards based only on vehicle size

† Sandalow. "Freedom from Oil" 2008.

Funding Deployment of Renewables

Currently, solar photovoltaics and concentrating solar power are more expensive than traditional electricity

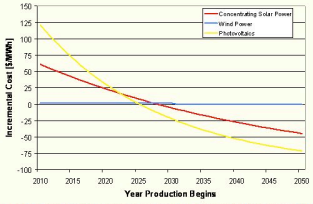


Figure 11: Incremental costs of renewable energy technologies 2010-2050

The federal government should subsidize electricity generated from wind, CSP, and PV based on the incremental cost over traditional electricity in the year generation begins.

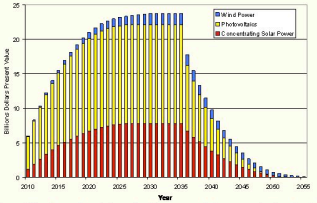


Figure 12: Annual costs to subsidize renewable energy technologies

Carbon Cap-and-Trade Policy

Regulate emitters over 10,000tC/yr (83% of U.S. emissions)

Establish an emissions target each year for those emitters

Auction carbon allowances equal to that emissions target

Reinvest revenues to subsidize renewable energy technologies

Allow regulated emitters to buy and sell allowances from each other

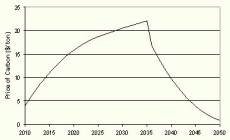
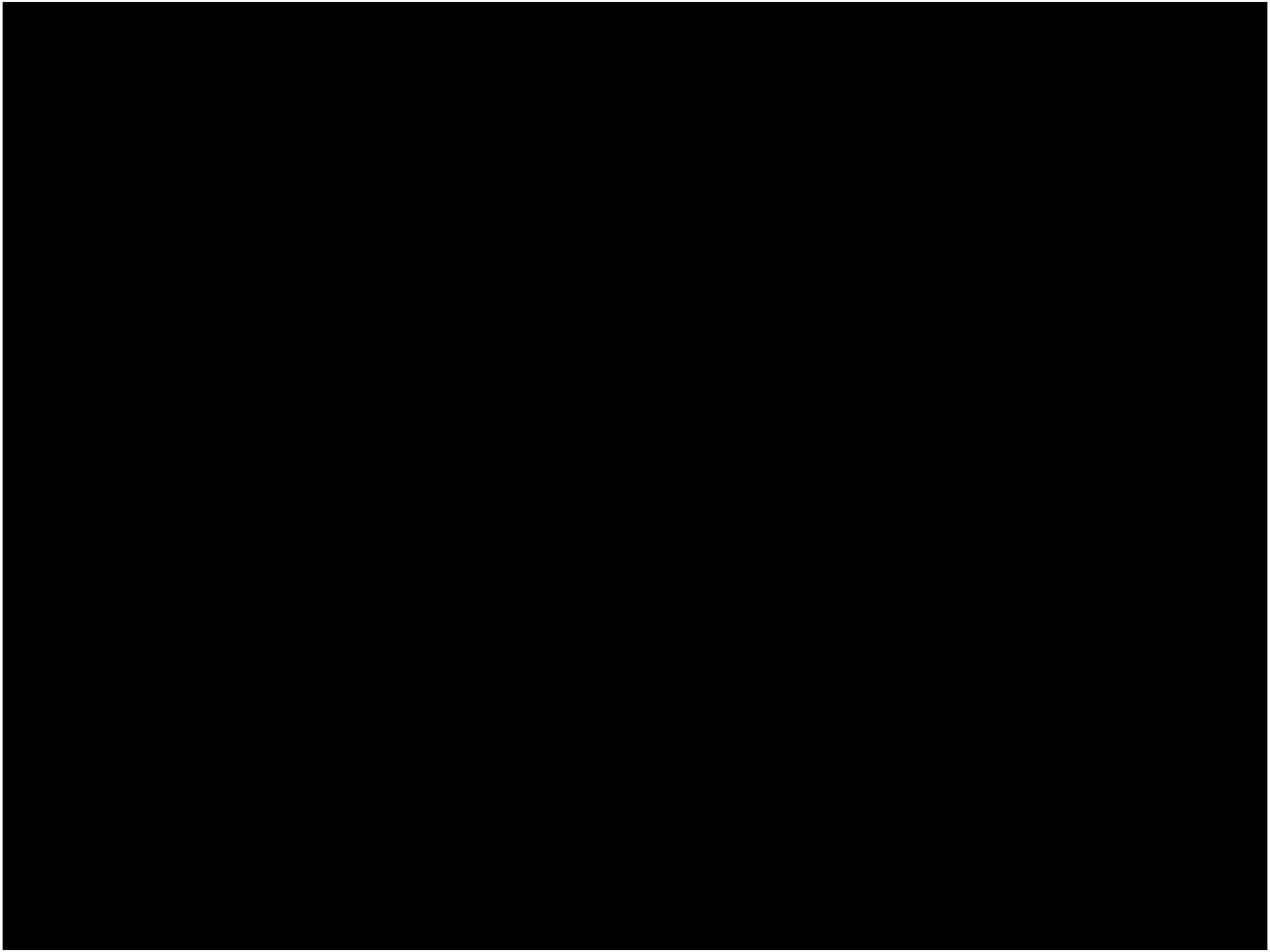


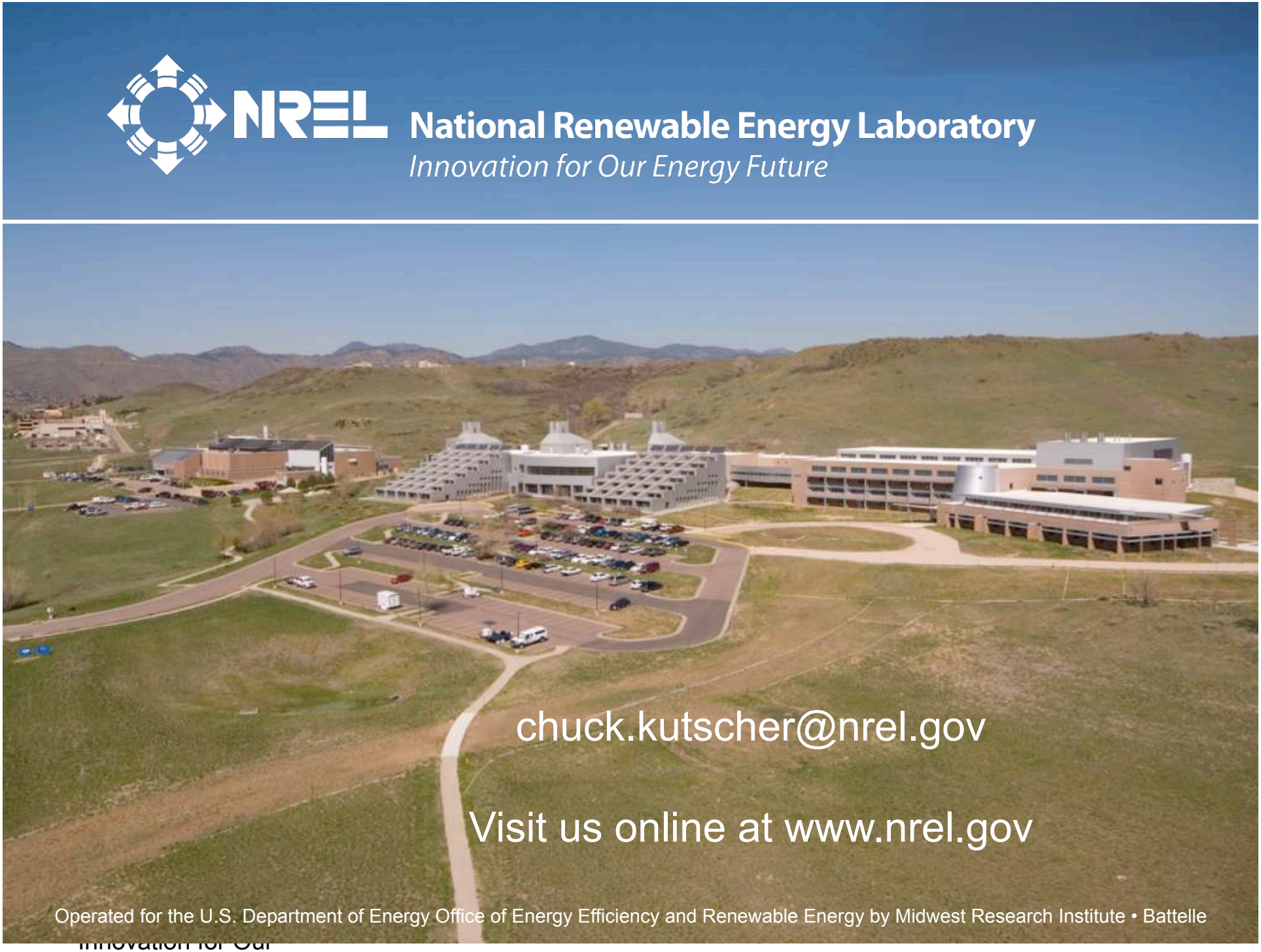
Figure 13: Price of carbon required to subsidize renewable energy

Conclusions

- Climate change is a real and pressing issue
- Stabilization at 450 ppm CO_2 will avoid the most devastating consequences
- The U.S. can achieve the necessary carbon emission reductions through energy efficiency and low-carbon electricity
- Renewable energy deployment will be subsidized with revenue from a cap-and-trade policy
- Marketing and regulation will be used to promote energy efficiency improvements

the **POWER** of csp





Energy Future