Solar Thermal Technology

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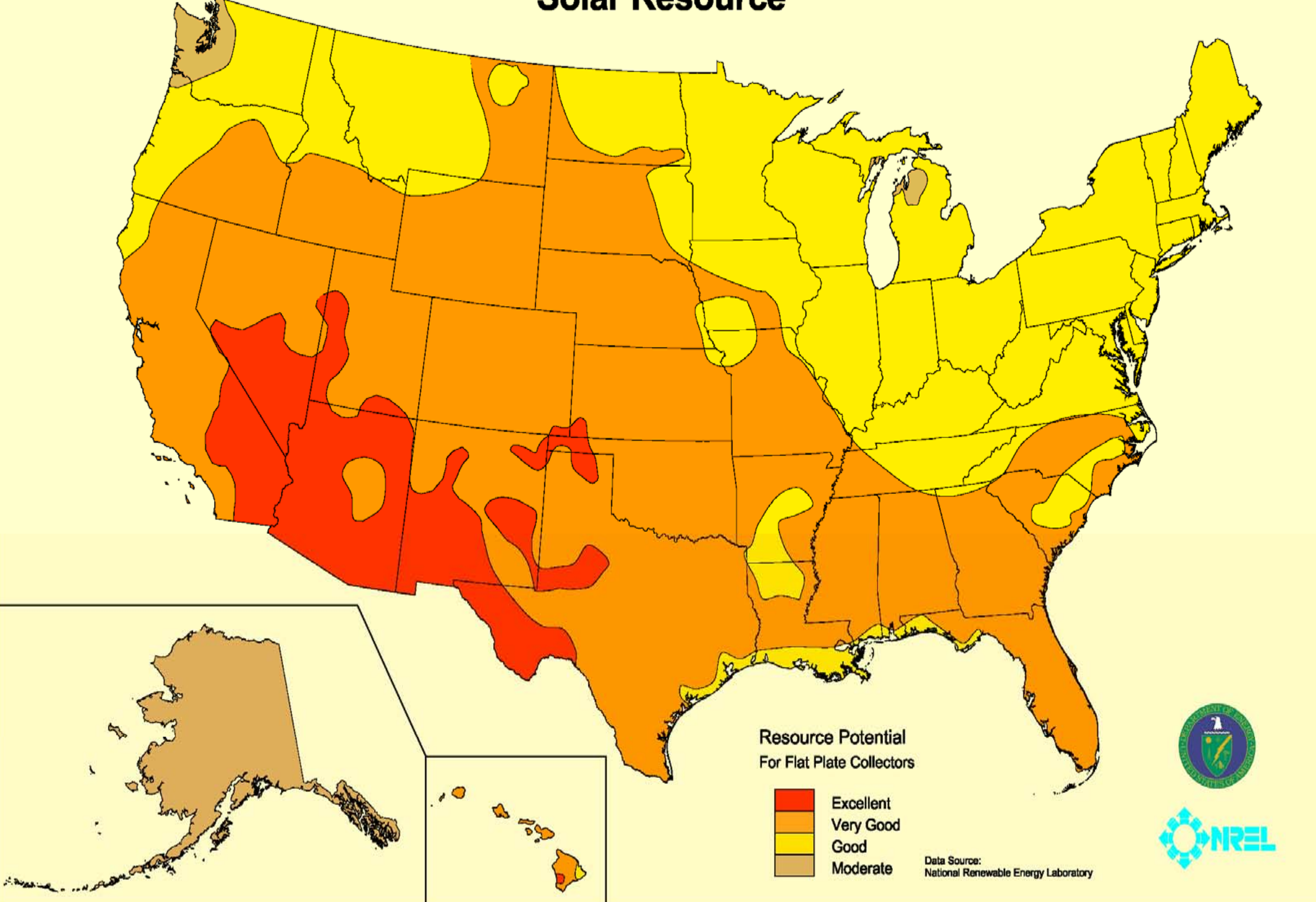
Sustainable Energy 10.391J, etc.

Solar Thermal

- Resource characteristics
- High temperature for electric power generation
- Medium temperature for water heating and “active” building solar heating (human comfort)
- Low temperature “passive” building solar heating (human comfort)
- Heat for industrial processes

Solar Resource

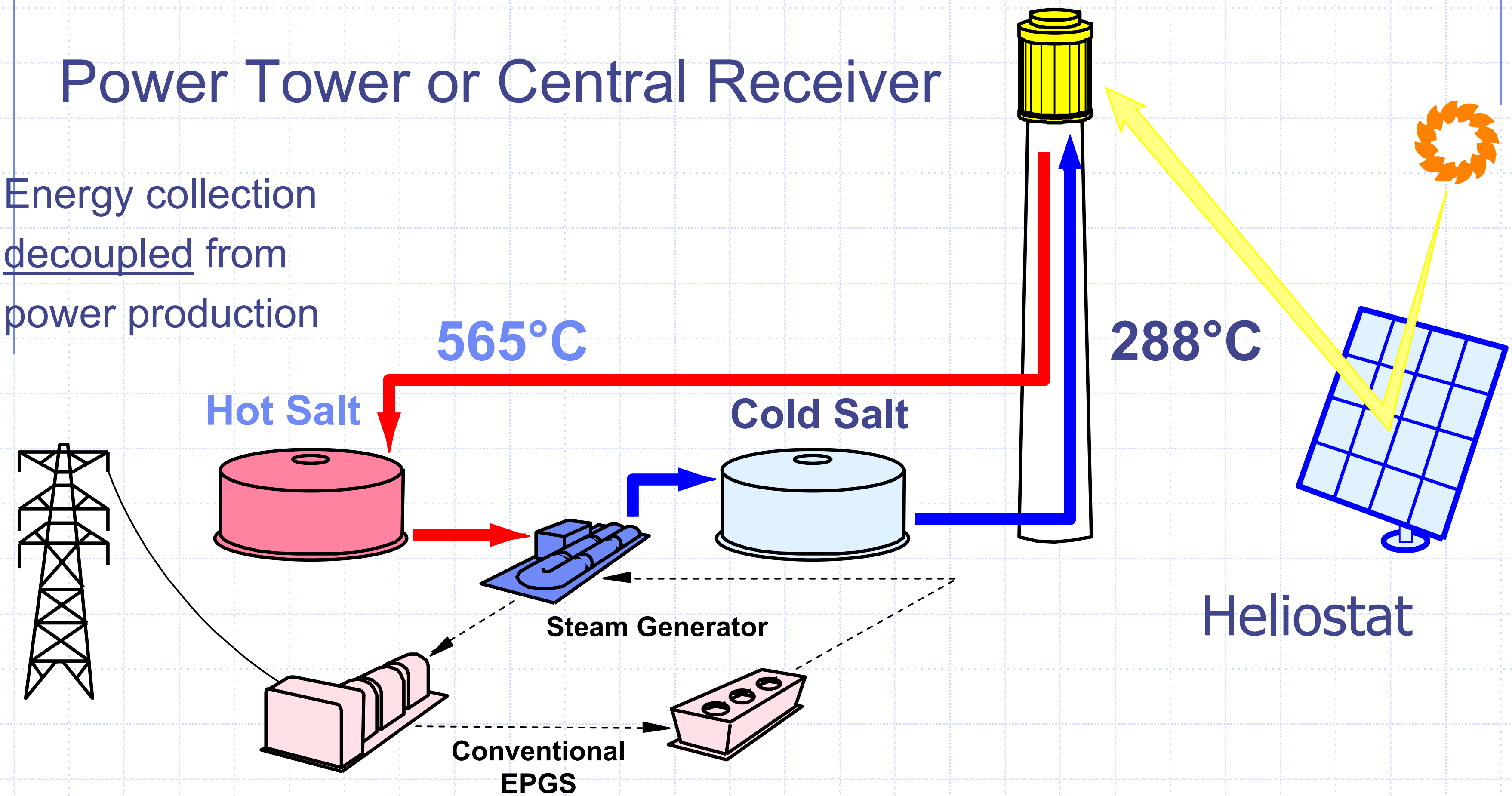


Solar thermal using concentrators

- Focusing requires direct, non-diffuse component
- Storage or hybridization needed to be dispatchable
- Central station option -- power towers 10 – 100 MWe
- Distributed mid size capacity -- parabolic troughs 1 -10 MWe
- Distributed smaller scale 10 kW -1 MWe -- dishes
- Medium temperature for water heating and “active” building solar heating/cooling of buildings (HVAC)
- Low temperature “passive” building solar heating
- Industrial process heat

Power tower with molten salt storage

Energy collection decoupled from power production



Courtesy of U.S. DOE.

Power Towers

Courtesy of U.S. DOE.

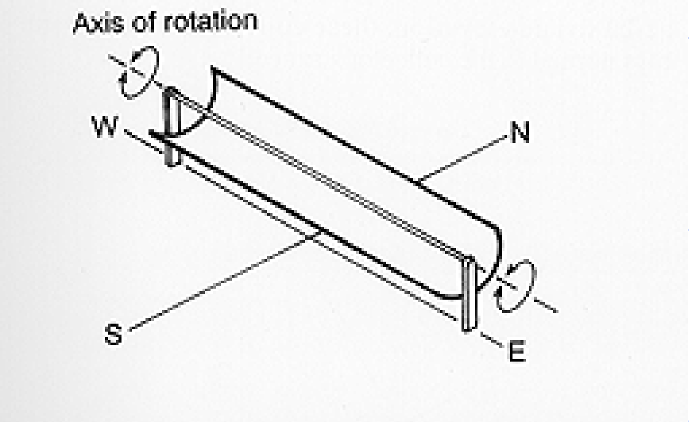
Heliostat Fields

- Current heliostat prices \$125 to \$159 m^{-2}
  - Reduction potential from manufacturing scale-up
  - Innovative Designs
- Compare with trough and PV

Courtesy of SunLab (Sandia National Laboratories and NREL partnership).

Parabolic Troughs

- Developed by Luz for use in California in 1970s
  - Slowed thinking about large scale PV
- Dispatchable hybrid design with natural gas backup – no storage
- Participated commercially in 1980s CA green power markets
- 354 Megawatts installed by 1991 at Kramer Junction, CA still operating today



One-axis tracking parabolic trough with axis oriented east-west

Courtesy of NREL.

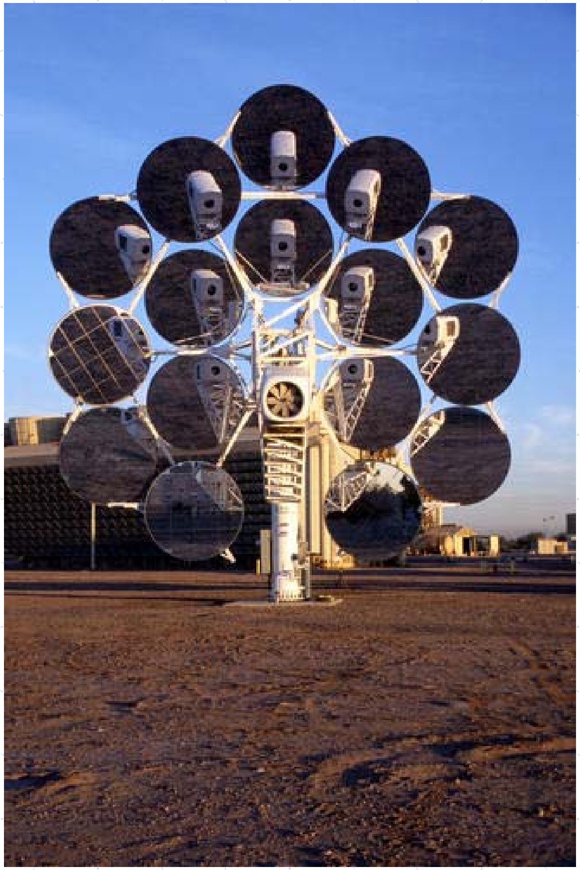
Luz International

- Failed commercially in 1992 from:
  - Low natural gas and electricity prices
  - High maintenance cost
  - Lack of certainty about tax incentives
- Restructured company still in operation at Kramer Junction
  - Along the learning curve on O+M innovations, e.g. receiver replacements and upgrades, storage, cleaning, etc.

Courtesy of SunLab (Sandia National Laboratories and NREL partnership).

Dish technology with Sterling cycle power generation

- Small scale distributed applications
- Of great interest to high tech industries and consultants
- Moving parts with 2-D tracking
- Exposed mirrors
- Shading and land use considerations



Courtesy of SunLab (Sandia National Laboratories and NREL partnership).

Solar Thermal Chimney

- Heated air, being less dense, rises in tower; thermal source from ground based thermal collector around perimeter
- Concept uses a wind turbine in the tower flow to extract energy
- Conceptual designs for India and Australia

Figure removed for copyright reasons.
Source: New York Times.

The Prototype Manzanares Solar Chimney, Spain

- Manzanares (south of Madrid).
- Delivered power from July 1986 to February 1989 with a peak output of 50 kW.
- Collector diameter of 240 meters, with surface area of 46,000m^2.
- Chimney was 10 meters in diameter and 195 meters tall.

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Source: New York Times.

Not very practical or economic

Figure removed for copyright reasons.
Source: New York Times.

Solar Heating of Buildings

- **Active Systems**
  - Can be captured in fixed or tracking modes using flat plate or focusing collectors
  - Even with storage needs backup supplemental supply
  - Early history had many failures – robust systems now
  - In today's markets are easily supported with subsidies in mid to high grade regions available
- **Passive Systems**
  - Vary from ancient to high tech designs
  - Require integrated designs for highest payback

Figure removed for copyright reasons.
Source: New York Times

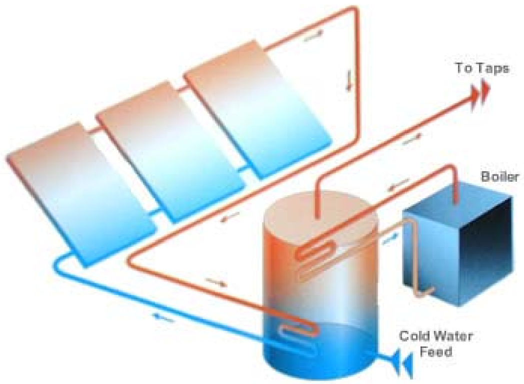
Solar Cooling of Buildings

- Active solar energy capture used to power Rankine refrigeration cycle
- LiBr absorption air conditioning for large building(s)
- Thermal storage may be required

Courtesy of NREL.

Heating Water

- Fast growing under Carter Administration
- Potential for 20-30% capture and use for year round water heating demands
- Subsidies in US led to rush to manufacture and install
- Quality was compromised and when subsidies were cut off market collapsed
  - Lesson has been learned by PV advocates



Courtesy of NREL.

Space & Water Heating Barriers

- No subsidies to defray initial cost from restructuring of electric companies (only US source of renewable energy subsidies)
- Little infrastructure to provide service
- Overcoming bad reputation from the 1980’s

Passive Solar

- Southern openings
- Thermal mass for diurnal stabilization
- Window technolgy to accept winter and reject summer direct radiation
- Hard to characterize and promote since all south facing glass is passive solar

Courtesy of U.S. National Park Service.

Solar thermal summary -- part 1

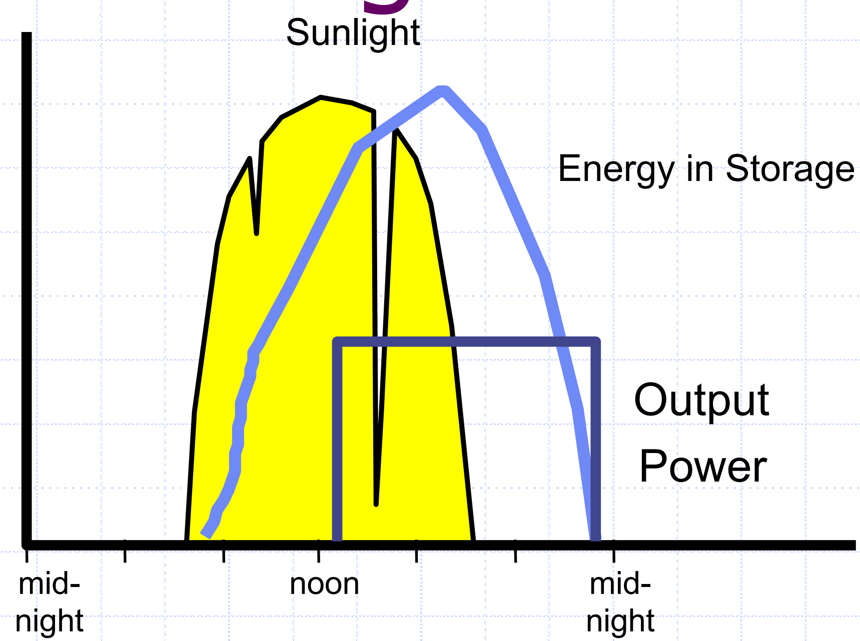
- Central station electric power
  - Wide areas of high temperature collection involving tracking devices
  - Must have high direct normal resource and lots of land, access to transmission lines
  - Thermodynamic cycle efficiency at end of process – upper limit of 35 to 40% heat to power efficiency
  - Thermal storage enables dispatchability

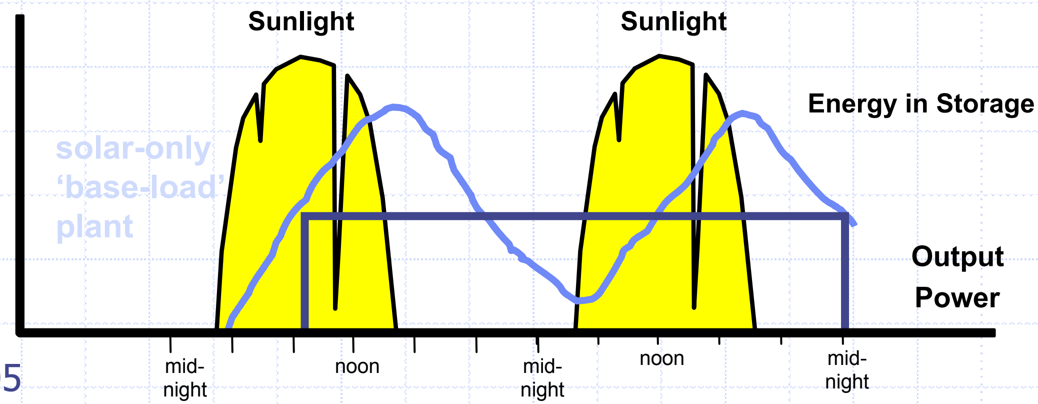
Solar thermal summary-- part 2

- Distributed electric power generation
  - Requires direct normal resource, tracking and concentrating issues
  - Potential for smaller scale installation using troughs and dishes
  - Heat to power conversion still limits performance to 30 to 40% efficiency
- Solar thermal heating
  - Passive and active system opportunities
  - Wide applicability for domestic water heating, less for space heating and cooling
  - Market growth provides better service infrastructure and more robust technology

Value of Thermal Storage

- Storage benefits
  1) Lowers LEC
  2) Increases market value
  - Dispatch to meet peak loads
  - operation through clouds
  - Capacity factors >70% possible
- "Solar salt"

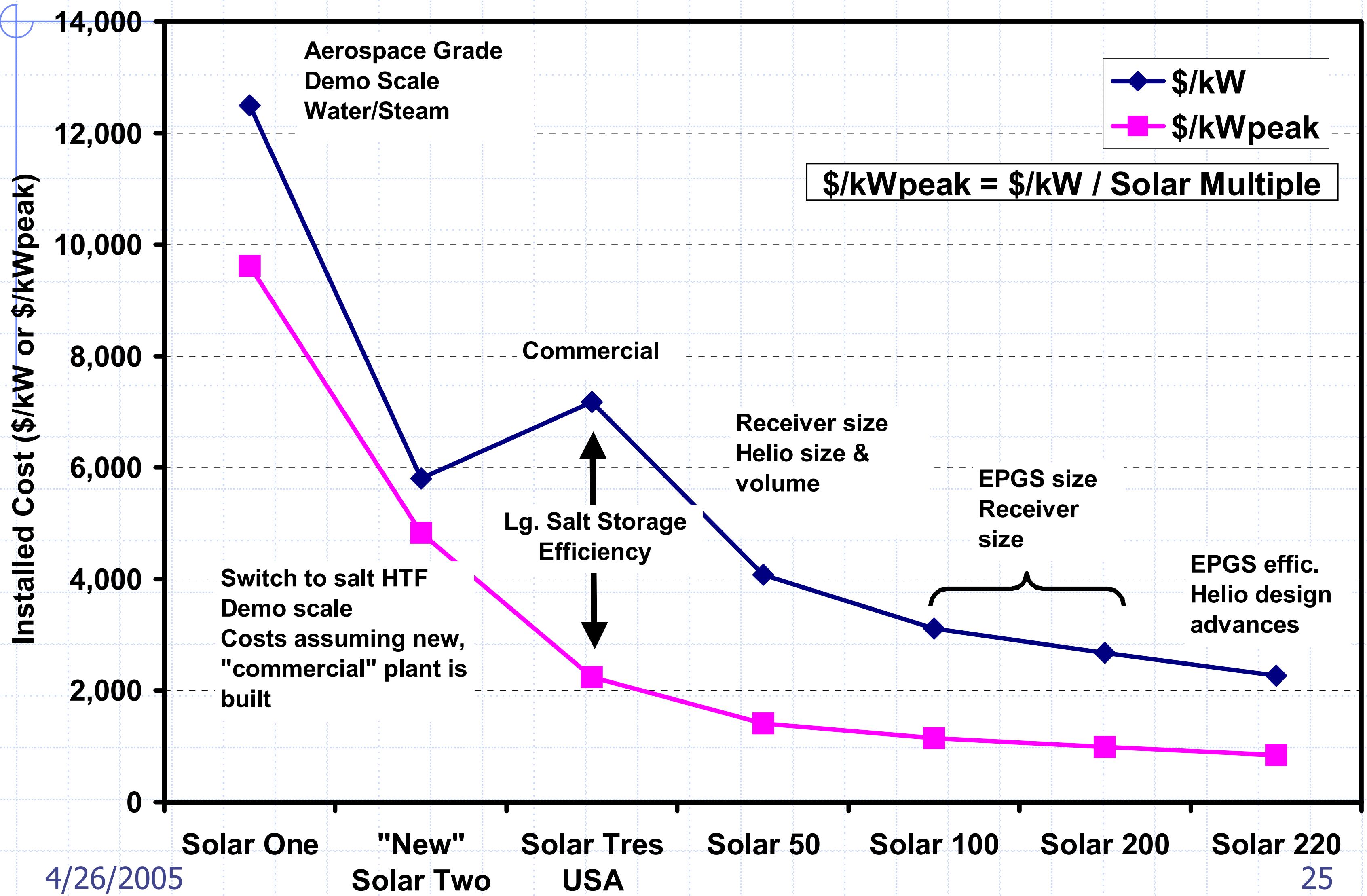




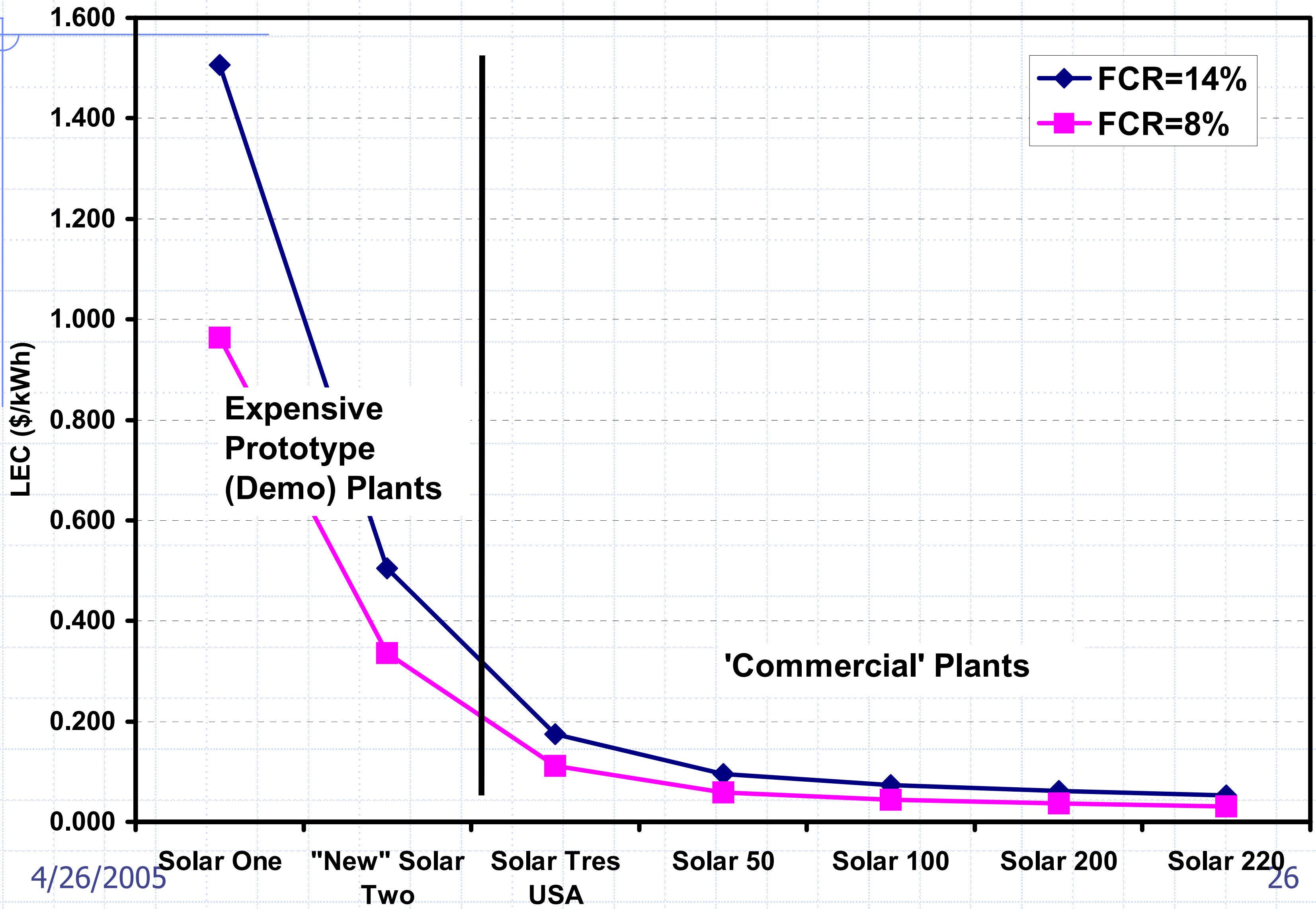
Tower Technology Projections

		Solar One	Solar Two	Solar Tres USA	Solar 50	Solar 100	Solar 200	Solar 220
Design Details	Units	1988	1999	2004	2006	2008	2012	2018
Plant output, net	MWe	10	10	13.7	50	100	200	220
# Plants built (A)	Volume	1	1	1	5	22	6	1
# Plants built (B)	Min Volume	1	1	1	1	1	1	1
Heliostat size	m^2	39	39/95	95	95	148	148	148
Heliostat type		Std	Std	Std	Std	Std	Std	Adv
Storage Duration	hours	N/A	3	16	16	13	13	13
Rankine Cycle								
Pressure	Bar	125	125	180	180	180	180	300
Live steam Temp	C	510	510	540	540	540	540	640
Reheat #1 Temp	C			540	540	540	540	640
Reheat #2 Temp	C						540	640
Number of staff		32	33	30	38	47	66	67

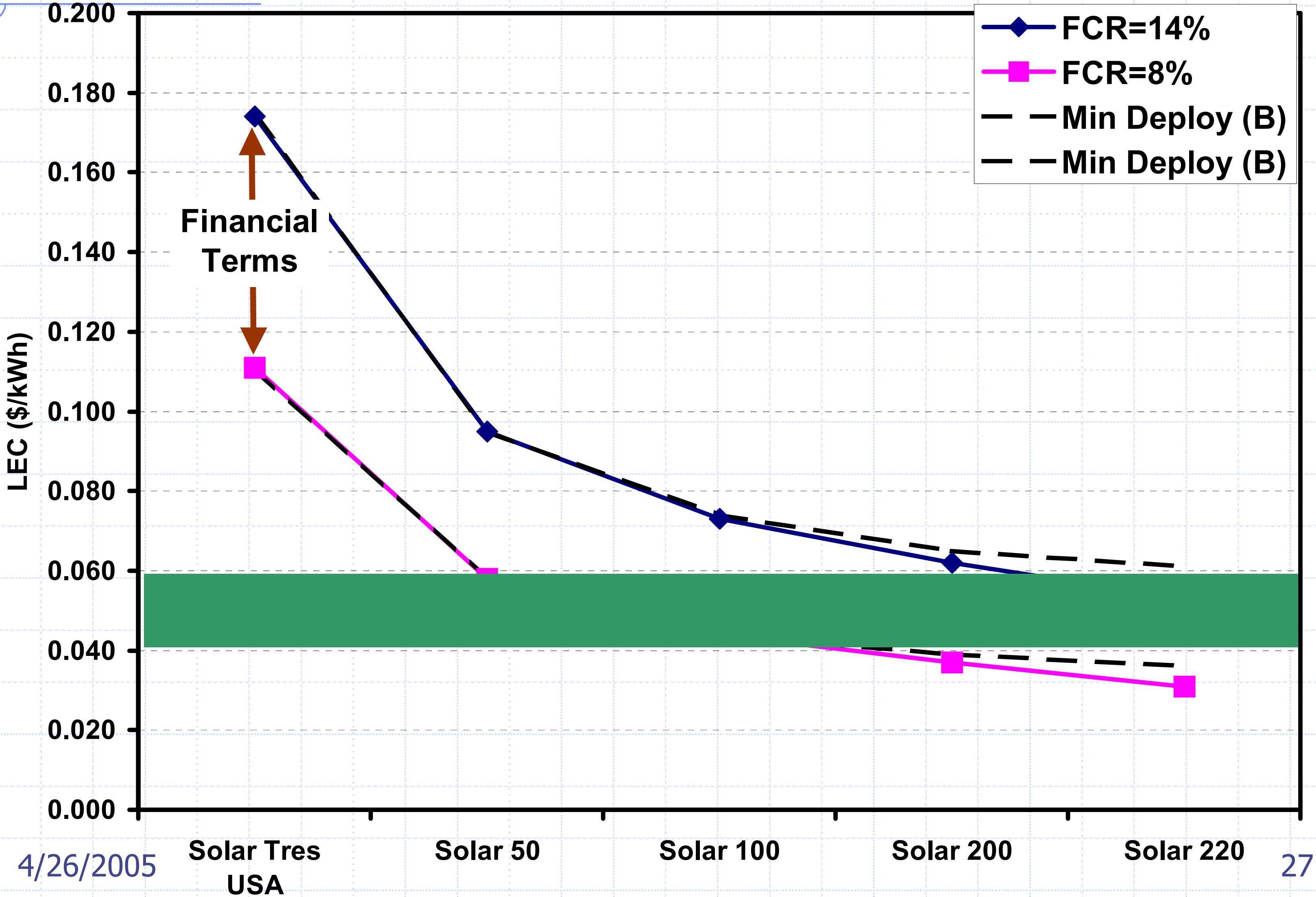
Tower Installed Cost



Tower Levelized Electricity Cost (LEC)



'Commercial Plant' LEC



Heliostat Cost

- Current heliostat prices
  - Numerous studies by industry, labs
  - A.D. Little 2001 study estimated price at $128/m^2$ installed (not including $5-10/m^2$ for controls)
  - Spanish company public offered heliostats for sale at $120/m^2$
  - $145/m^2$ used for Solar Tres USA
- Cost Reduction

Courtesy of SunLab (Sandia National Laboratories and NREL partnership).