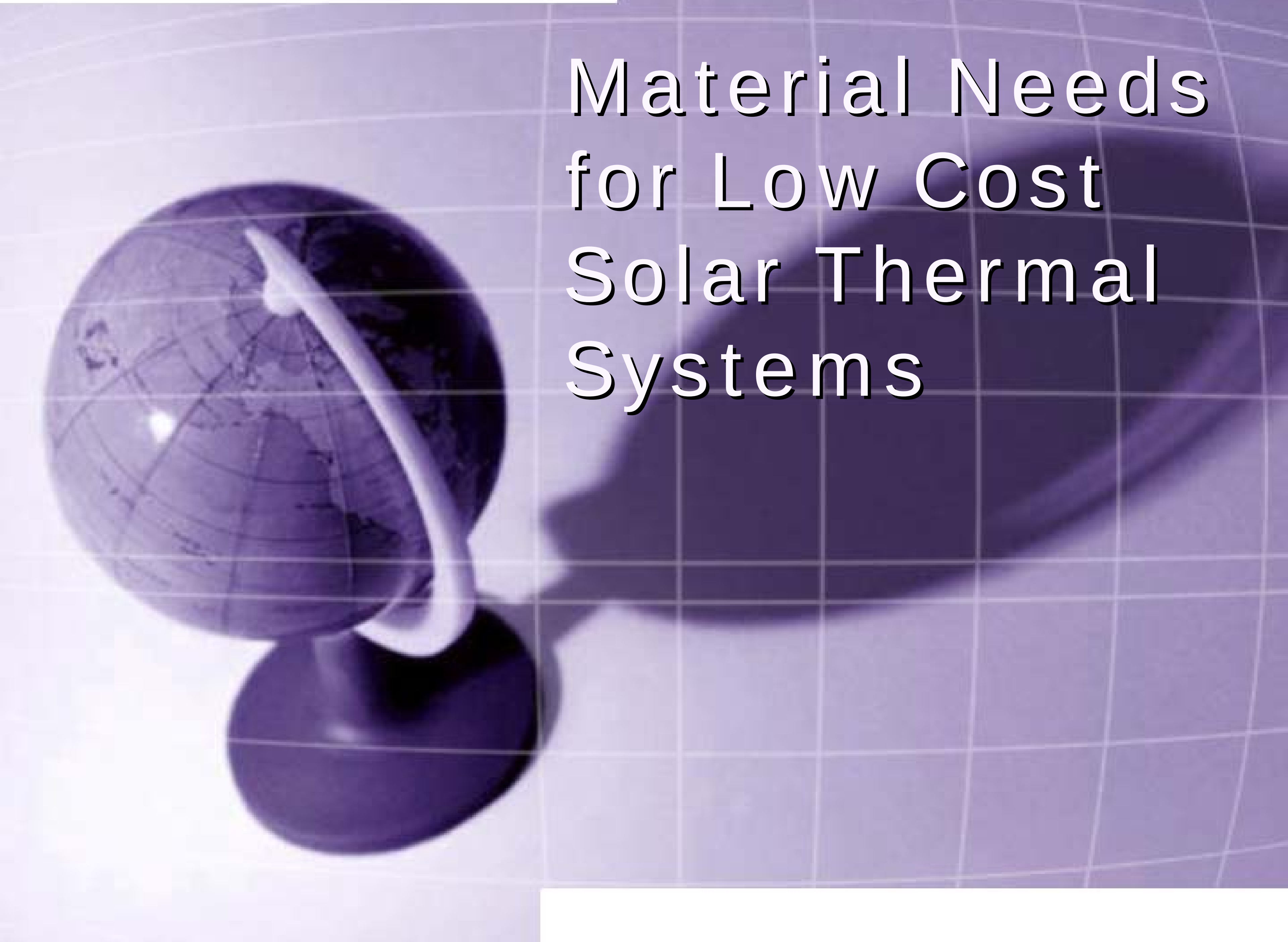
Material Needs for Low Cost Solar Thermal Systems



Fixed Input to Concentrated Solar Thermal (CST)

Extraterrestrial Radiation

Solar Spectral

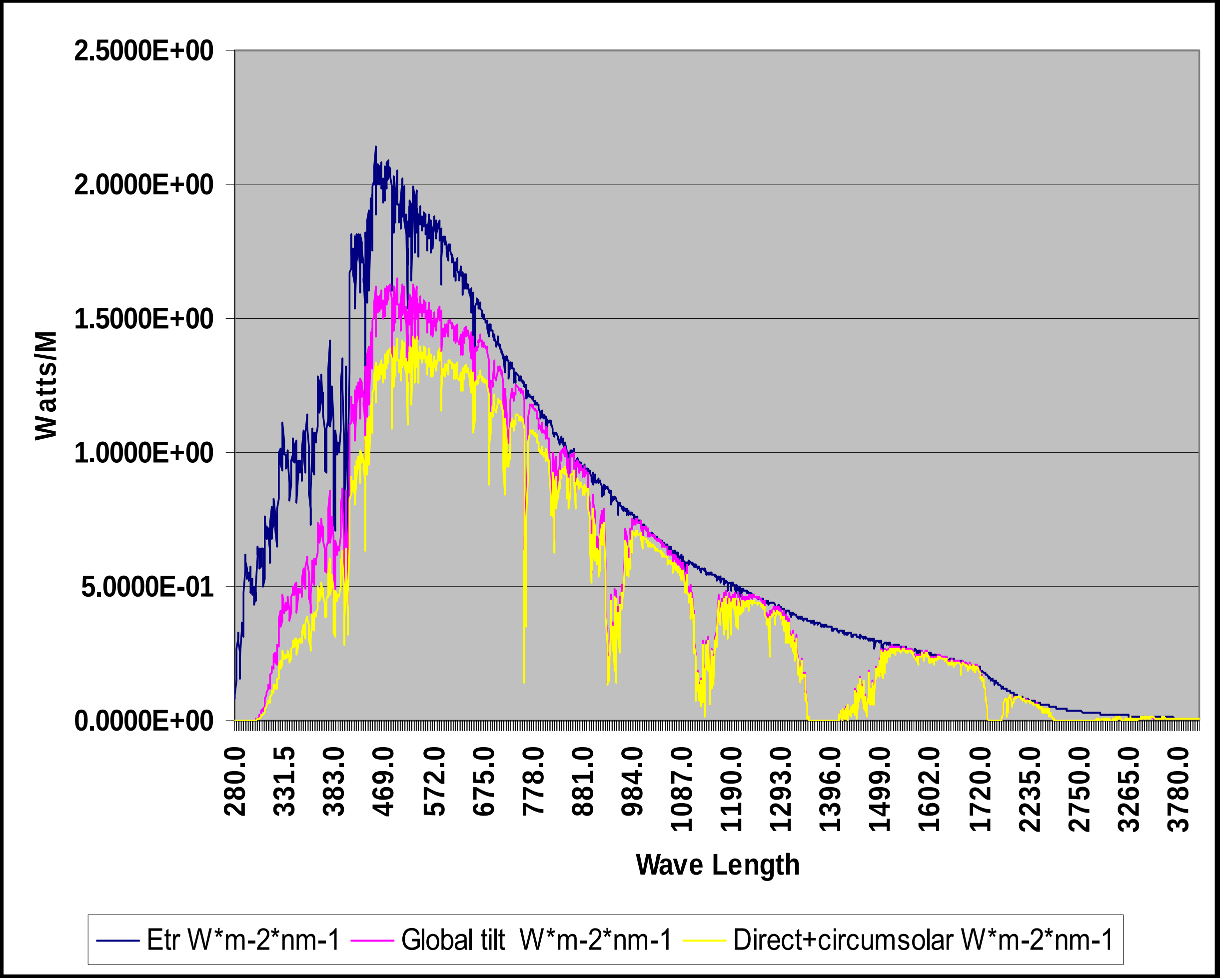
(ASTM G173-03 Reference Spectra Derived from SMARTS v. 2.9.2)

Circumsolar Radiation - the amount of solar radiation coming from a circle in the sky centered on the sun's disk and having a radius of between 2.5 and 3.5 degrees, depending on the type of instrument being used to measure beam radiation (direct normal irradiance).

Direct Normal Irradiance - synonym for beam radiation, the amount of solar radiation from the direction of the sun.

ETR - extraterrestrial radiation, also known as "top-of-atmosphere" (TOA) irradiance, is the amount of global horizontal radiation that a location on Earth would receive if there was no atmosphere or clouds (i.e., in outer space).

"**Global Tilt**" = spectral radiation from solar disk plus sky diffuse and diffuse reflected from ground on south facing surface tilted 37 deg from horizontal



Total Solar Spectral Radiation

Integrating Under Each Curve:

- **ETR** (extraterrestrial radiation) = **1,356W/m²**
- **Global Tilt = 1,003W/m²**
- **Direct Normal Irradiance+ Circumsolar Radiation = 887W/m²**

Six Components of CST

- Receiver (heat exchanger)
- Reflectors (mirrors)
- Support Structure (for mirrors and receiver)
- Tracking (mechanical)
- Control (SCADA, HMI, Tracking)
- Piping

These components along with a thermic fluid to water heat exchanger form the equivalent of the boiler.

Cost Contribution of Each Component

- Receiver ≈ 13% to 17%
- Reflectors ≈ 16% to 24%
- Supporting Structure ≈ 35% to 50%
- Tracking ≈ 20% to 24%
- Control ≈ 1% to 1.5%

Raw data provided by Ashvin Shah, Estimated Costs of Solar Thermal and Electrical Energy, August 1999

It is the reflector that has gained the majority of the attention.

Solar Reflectors

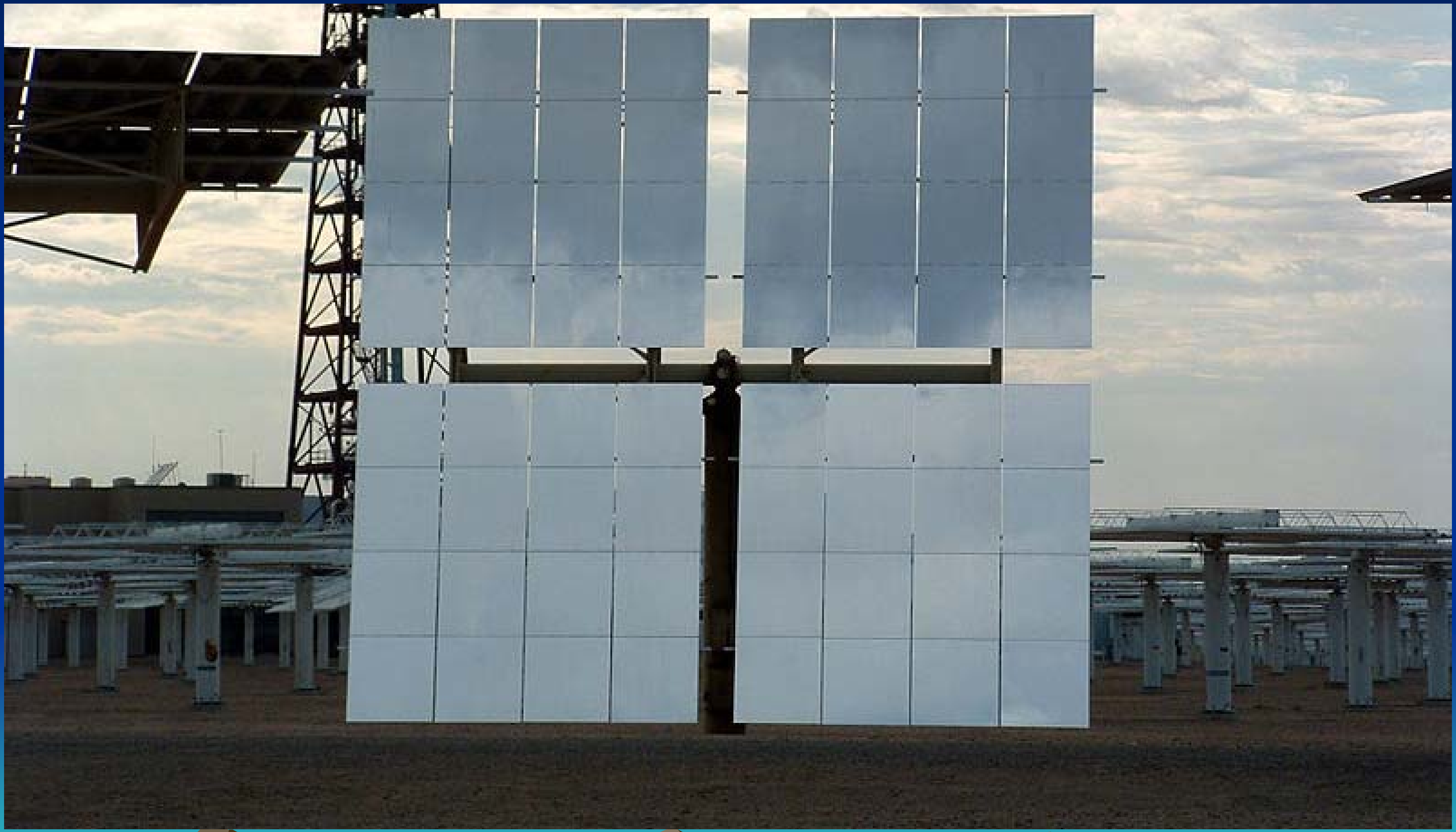
for Concentrated Solar Power (CSP)

- There are five widely accepted solar concentrator approaches in use.
- Majority of applications utilize metalized (Al or Ag) second surface mirrors. Fabricated using low iron glass (white glass).
- Depending on the CSP technology employed, in general, mirrors are elastically formed (glass <1mm thick), slumped glass (typically 3mm thick) or flat.

Power Towers

Solar Two located in the Mojave Desert of California.

Solar Two Heliostat (Flat Glass)



Parabolic Trough

Euro Trough during construction in Granada Spain

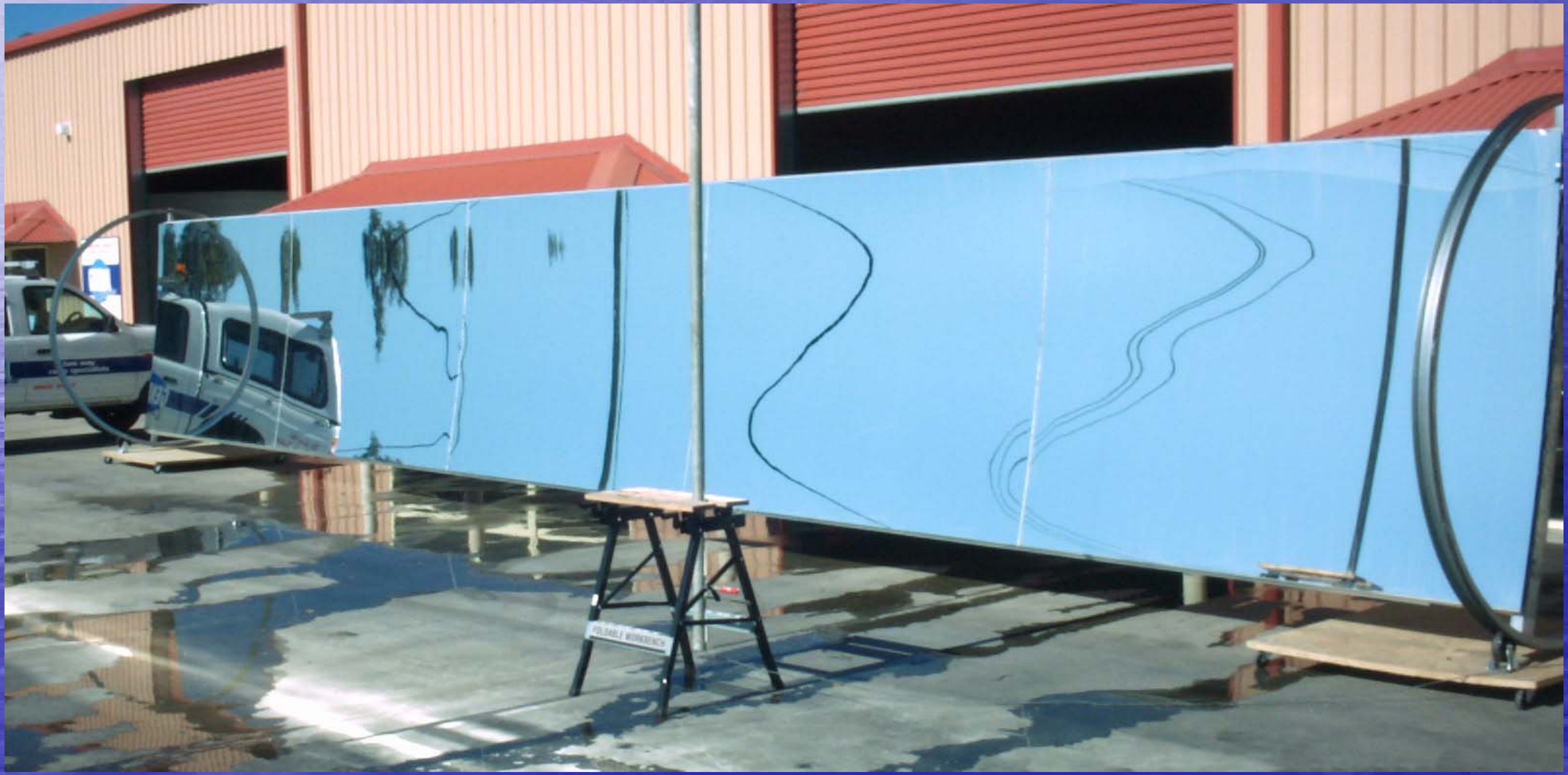
Euro Trough
(Single Curved Slumped Glass)

CLFR (Compact Linear Fresnel Reflector)

Liddell Plant near Muswellbrook

CLFR

(Elastically curved reflectors, The Solar Energy Group @ The University of Sydney)



(implementation Photographs by David Mills of ASURA)

Parabolic Point Concentrator
(Double Curved Slumped Glass)

Power Towers

- Solar Two utilized 1,926 heliostats totaling 82,750m² (120We/m²) on 126 acres of land.
  (“Solar Two The Solar Project”, Wikipedia)
- While in operation between 1996 and 1999 this facility produced 10 megawatts of electricity at a cost of $48.5 million ($4.85/We, $586/m²) .
  (“Sandia Labs Shares Major Solar Success With Industrial Consortium”, Chris Miller, Sandia Labs, June 5, 1996)
- More recently in 2007, a solar power tower project was completed in Spain with a nominal power capacity of 11MWe totaling 74,880m² (147We/m²), at a cost of $47.8 million ($4.35/We, $638/m²).
  (“First EU Commercial Concentrating Solar Power Tower Opens in Spain”, March 30, 2007, ENS)

Parabolic Trough

- Euro Trough in Granada Spain operating since 2006 produces 49.9 megawatts of electricity + 6Hrs storage + 25% reserve using 510,120m² of mirrors (255 W_e/m²) at a cost of $390 million ($2.99/W_e, $765/m²).
  ("AndaSol-I and AndaSol-II", Antonio Gomez, Marcello Formica)
- The Nevada Solar One trough plant completed in 2007 produces 64 megawatts of electricity with a mirror area of 357,000m² (179 We/m²) costing $220 million, ($3.44/We, $616/m²).

CLFR

- Stage I CLFR installed near Sydney Australia using 1,380m² mirrors producing 1megawatt thermal.
  (“First Results from Compact Linear Fresnel Reflector”, Mills, Livere, Morrison)
- Stage II this facility is expected to produce 4.4megawatts electric using 17,000m² mirrors (258W_e/m²) at a cost of ($A7 million) $US4.7 million ($1.07/W_e, $276/m²).
  (“Stanwell Solar Thermal Power Project”, Burbidge, Mills, Morrison)

Parabolic Point Concentrator

- The SES (Sterling Energy Systems) 87m² dish, one of six installed at Sandia National Laboratories in 2005.
- The combined output produces 150Kw of grid ready electrical power (287We/m² @ estimated $450 to $600/m²).

(PHYSORG.com, “New world record for solar-to-grid conversion efficiency”, Feb 3 2008)

The Challenge

- Cost
  - Assuming coal at \$90/ton (\$125/ton two months ago) and the construction cost of a fossil fuel plant at $\$2.25/W_e$, to compete CSP must achieve \$200/m² at $< \$2/W_e$.

Conclusion

- We know how to concentrate the sun and make steam.
- We don't know how to concentrate the sun and make steam at a cost that can compete with fossil fuel plants.

Major Cost Contributor

- The glass mirrors comprise 16% to 24% of the component cost.

- Adding in the portion of the structure used to support and stiffen the mirrors the cost is more like 50% for dish or heliostats, and 75% of a trough.
  (Kennedy; Terwilliger, "Optical Durability of candidate Solar Reflectors" International Solar Energy Conference July 2004)

Challenges to Low Cost Reflectors

- Industry drive for high optical efficiencies.
  - Requires low Fe glass.
  - Broad band high reflective metallization (Ag or Al).
    - 7% of terrestrial radiation resides in the UV band.
      - Ag 84% reflectance in the UV band
      - Al 92% reflectance in the UV band
    - 24% resides in the IR and near IR band.
      - Ag 99% reflectance in IR and near IR.
      - Al 98% reflectance in IR and near IR.
      - BK7 glass 64% in IR, 94%Near IR.
  - Broad band anti reflective coatings.
- Industry need for durability
  - Withstand load from winds of 30mph to 60mph while maintaining operation (100 mph is "off" position).
  - High humidity and rain.
  - Withstand dust and abrasion, organic and inorganic pollution
  - 10 years minimum life, prefer 20 years.

Challenges to Low Cost Reflectors

- These challenges are self imposed as a means of mitigating cost.
- How much more can the glass industry improve the efficiency and durability of their second surface mirrors? At what cost?
- Is there more that can be done to increase the strength such that structural costs can be decreased ?

Challenges to Low Cost Reflectors

- Are there new glasses or other reflector materials that can be implemented more economically? At what cost?
- Since reflective materials are multi-layers, technology improvements to seal edges for longer life. At what cost?
- Is there more that can be done to reduce the production cost of glass mirrors relative to other materials?

SUMMARY

- Concentrated Solar Thermal applications have a great deal of potential
- We don’t know how to concentrate the sun and do it at a cost that can compete with fossil fuel plants
- The reflectors/structure could be as much as 75% of cost of the “solar heater”
- What can the glass industry do to improve price-performance ratio?

THANK YOU FOR YOUR ATTENTION

QUESTIONS?????