



Solar Mirrors

*ASPERA Technological Forum
Oct 2011*

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Concentrating Solar Power (CSP) – Solar Thermal Power Plants

- Mirrors concentrate the sun light
- CSP uses **direct** sun light
- Absorb radiation at high temperature
 - 300-400 °C (classic trough), or more
- Use heat in conventional thermodynamic cycle (thermal power plant)
- Generate electricity
- Storage possible, dispatchability

Concentrating Solar Power Technology Options

Parabolic Trough



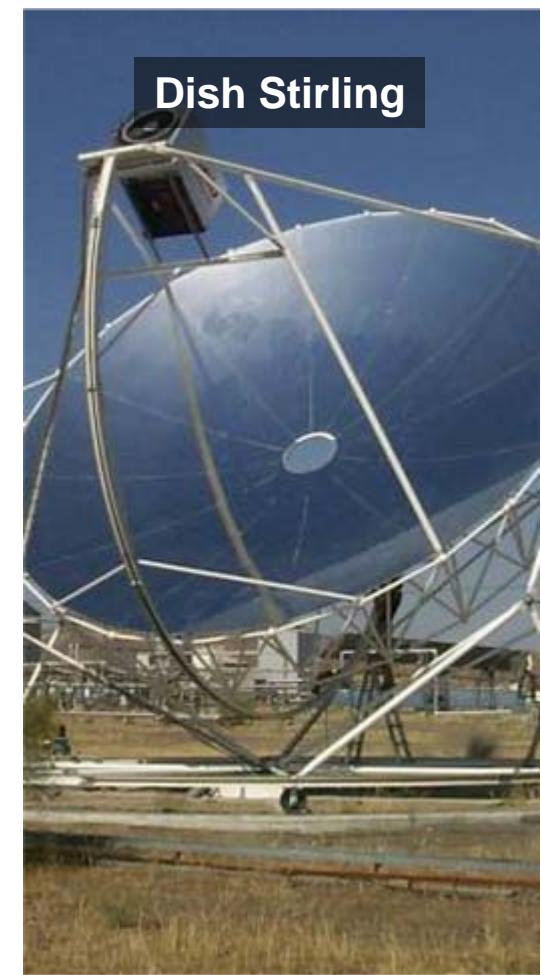
Linear Fresnel



Power Tower
Central Receiver



Dish Stirling



Concentrating Solar Power Technology Options

Parabolic Trough



Line focusing Systems
 $C \sim 80$

Linear Fresnel



Power Tower
Central Receiver



Dish Stirling



Point focusing Systems
 $C \sim 1000$

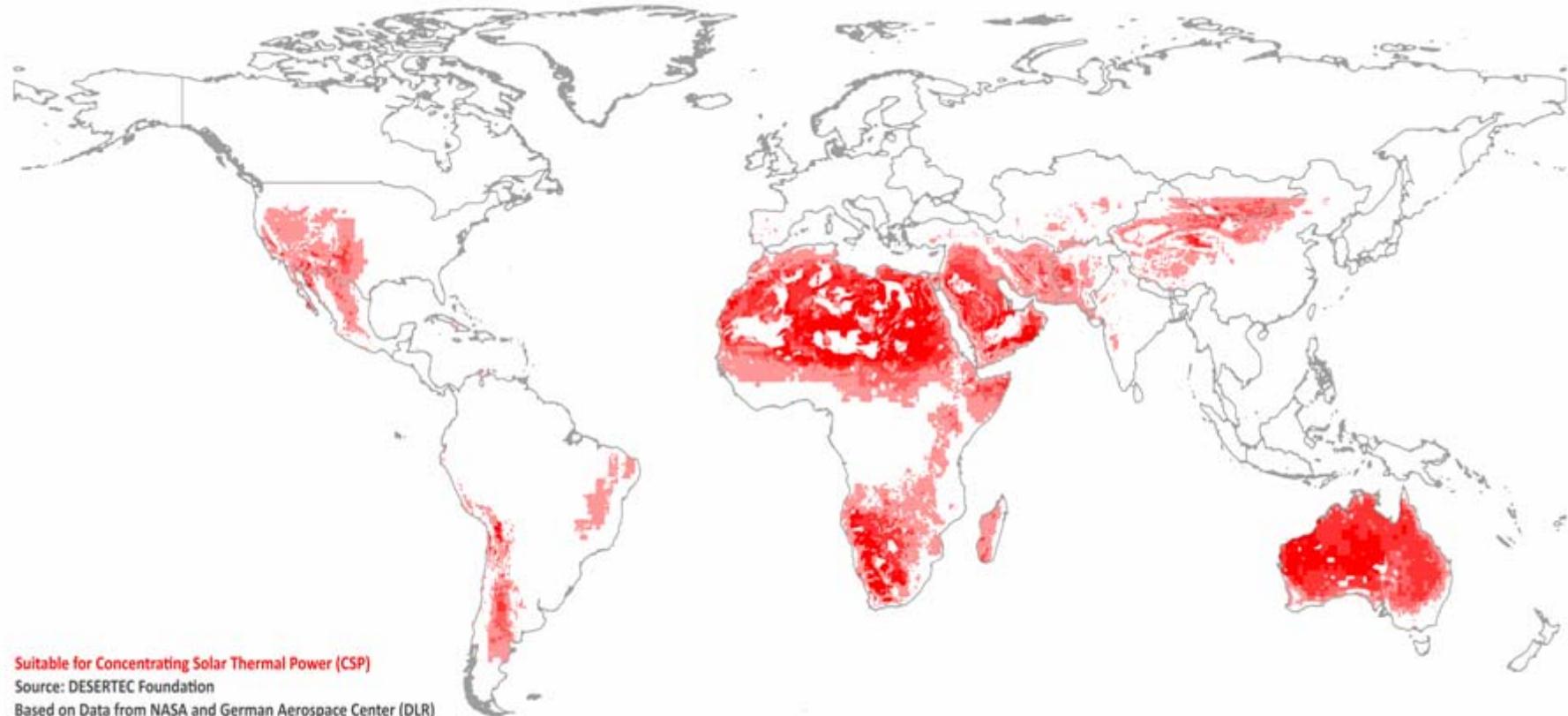
Status Receiver Technology – Heat Transfer Fluids

- Parabolic trough (> 95 % of market share)
 - Commercial: synthetic oil, storage, 400 °C (Solar Millenium, Sener, Abengoa, Siemens, Acciona, Iberdrola, FPL, ...)
 - R&D: superheated steam, molten salt, 550 °C
- Tower
 - Commercial: saturated steam (Abengoa)
 - Commercial: molten salt, 550 °C (Sener, Solar Reserve)
 - R&D: superheated steam, 550 °C (Brightsource)
 - R&D: air, 800 °C (Jülich KAM)
 - R&D: pressurized air (DLR, Abengoa)
- Linear Fresnel
 - Commercial: saturated steam (Novatec, AREWA)
 - R&D: superheated steam
- Dish-Stirling
 - He, H²

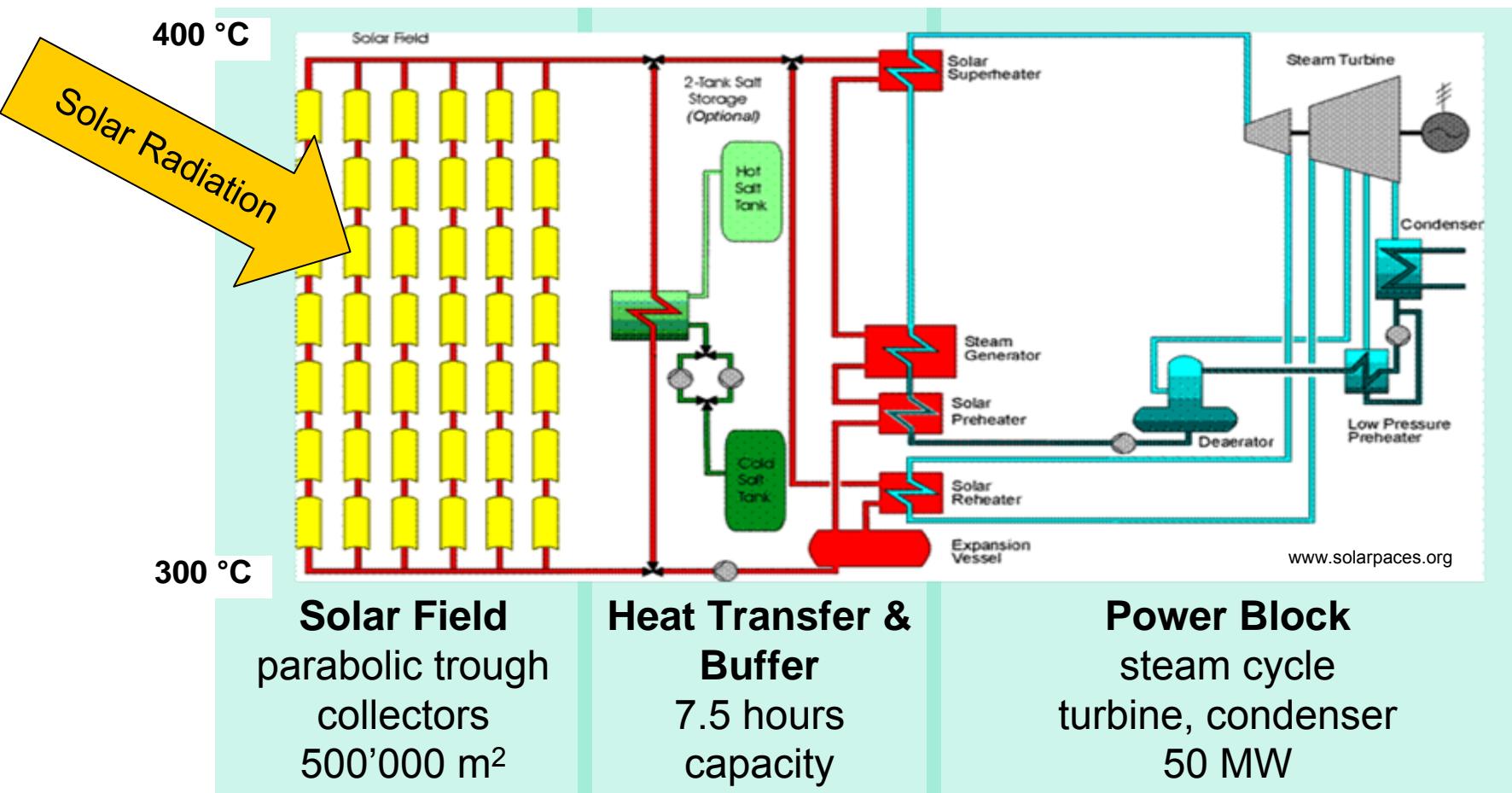
CSP History

- ☛ 1918
 - ☛ 1st Parabolic trough plant in Egypt by Shuman
- ☛ 1985-1990
 - ☛ USA, SEGS plants, parabolic trough, 354 MW
- ☛ 2004
 - ☛ Spain
 - ☛ Feed in tariff in Spain, 50 MW max., 0.275 €/kWh
 - ☛ 950 MW, 2011
 - ☛ 2.5 GW, 2013,
 - ☛ 95 % parabolic trough, mostly with storage
- ☛ Now
 - ☛ North Africa, Middle East, India, China, Australia
 - ☛ USA, several ~1 GW projects
 - ☛ Desertec DII (ABB, Siemens, Schott, Abengoa, Munic RE, Deutsche Bank, ...)
 - ☛ 15 % of electricity consumption of Europe by 2050
 - ☛ with Solar Thermal, PV, Wind, from North Africa 400 G€ investment
 - ☛ Mediterranean Solar Plan (France, Egypt)
 - ☛ 15 GW by 2020

Suitable Locations for CSP plants



Parabolic Trough Andasol Type Power Plant



Andasol 1-3 Spain

3x50 MW Solar Power, 3800 Full-Load Hours per Year



Andasol 1-3 plants 50 MW Spain



Mirrors for 50 MW Andasol Type Plant

| | |
|--|------------------------|
| ↗ Glass | 550 000 m ² |
| ↗ Mirror panels | 204 288 |
| ↗ Mirror fixation pads and bolts | 817 152 |
| ↗ Glass mass | 5700 t |
| | |
| ↗ Total investment | 300 M€ |
| ↗ Mirrors are 10 % of the total investment | |
| ↗ Mirrors are 20 % of the solar field investment | |
| ↗ Mirror investment | 30 M€ |
| | |
| ↗ Mirror price (parabolic trough) | ~ 60 €/m ² |

Mirror Types

State of the art

- ↗ Glass mirror (Flabeg, Saint Gobin, AGC, Rioglass)
 - ↗ Thickness 4-5 mm, hot bend for parabolic trough, solar glass, silvered back side, protection coating
 - ↗ $\rho \sim 94\%$

Options

- ↗ Thin glass (Saint Gobin)
 - ↗ Thickness ~2 mm, cold bend for parabolic trough, needs structure on backside
 - ↗ $\rho \sim 95\%$
- ↗ Aluminum (Alanod, Alcan)
 - ↗ $\rho \sim 88\%$
- ↗ Polymer (3M, Reflectec)
 - ↗ $\rho \sim 94\%$

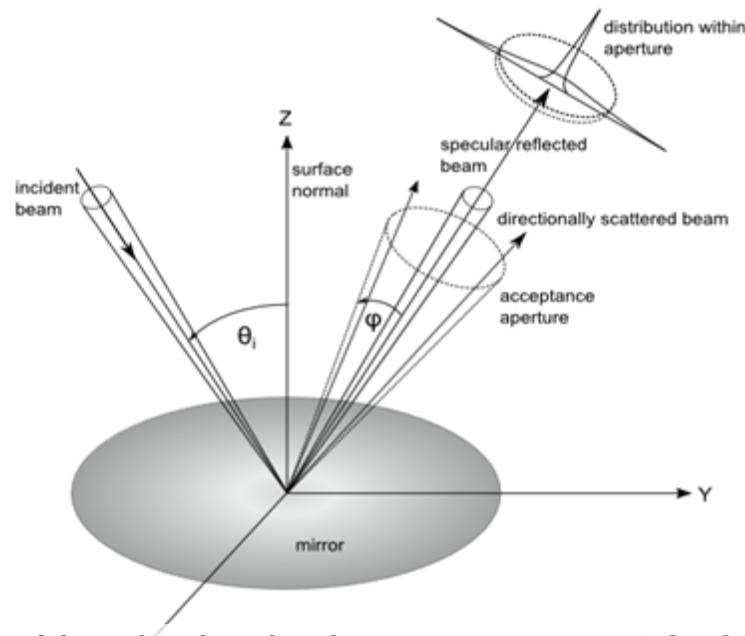
Concepts

- ↗ Anti soiling coatings

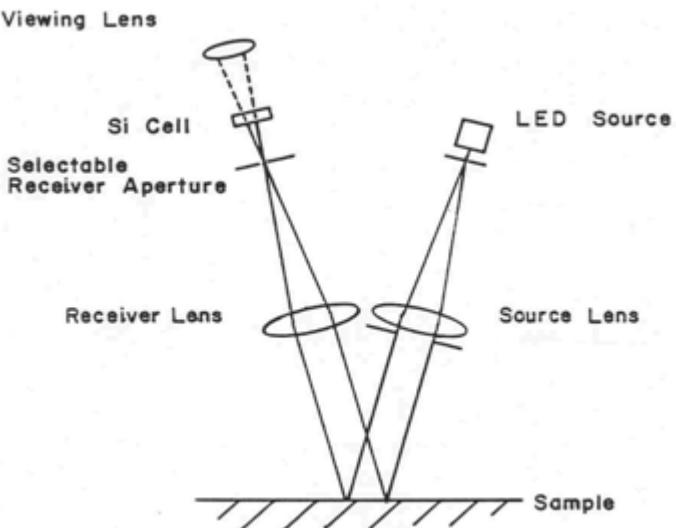
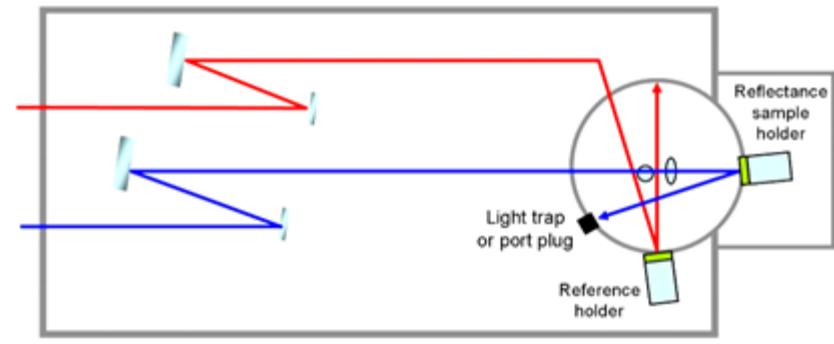
Mirror Properties and Measurement

- ☛ Desired properties
 - ☛ Cheap (parabolic trough ~ 60 €/ m²)
 - ☛ High reflectance, solar weighted direct reflectance > 90 %
 - ☛ Longevity (< 1 % loss/ 25 a)
 - ☛ High shape accuracy
- ☛ Measurement
 - ☛ Solar weighted direct reflectance
 - ☛ Shape
 - ☛ Ageing (UV, salt, acid, sandstorms, cleaning ...)

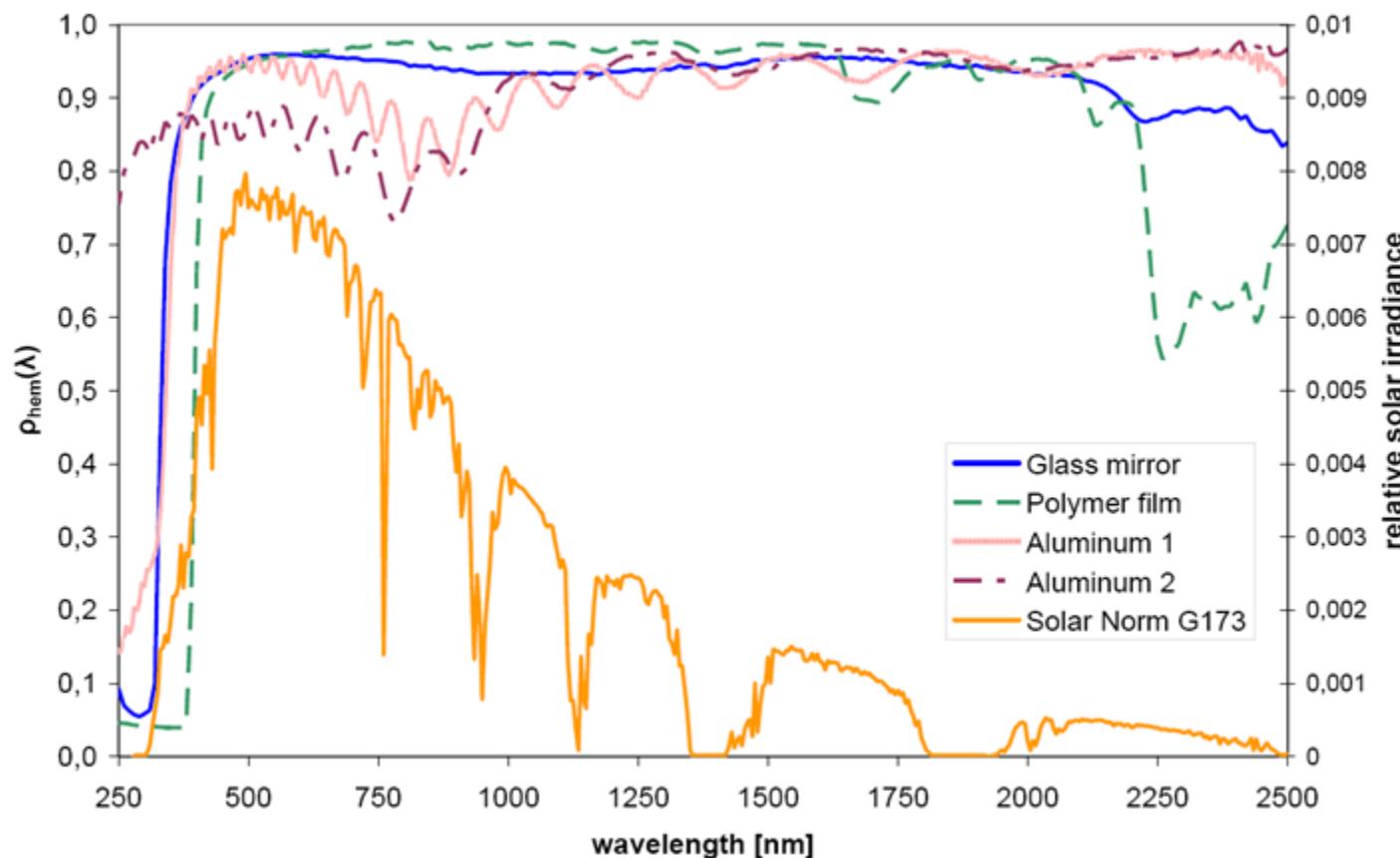
Reflectivity Measurement With Commercial Devices



- ↗ Hemispherical measurement 250...2500 nm
 - ↗ Spektrophotometer with integrating sphere, hemispherical measurement
- ↗ Specular reflectance at 660 nm into 25 mrad aperture,
 - ↗ Reflektometer D&S 15R



Hemispherical Reflectance of Solar Mirrors

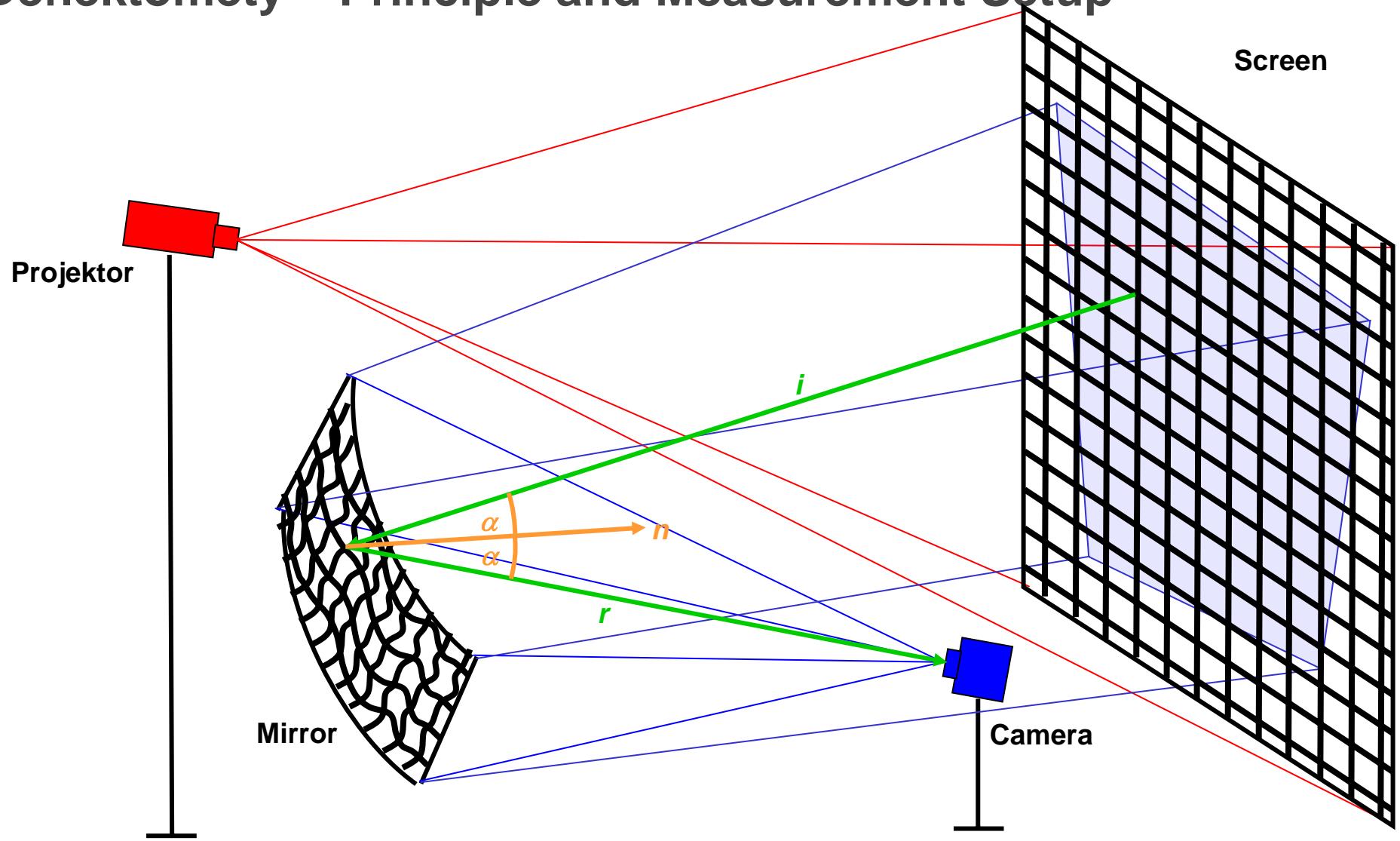


Meyen et al.: Optical Characterisation of Reflector Material for Concentrating Solar Power Technology,
Proceedings of Solar PACES Conference, Berlin, 2009



Shape accuracy

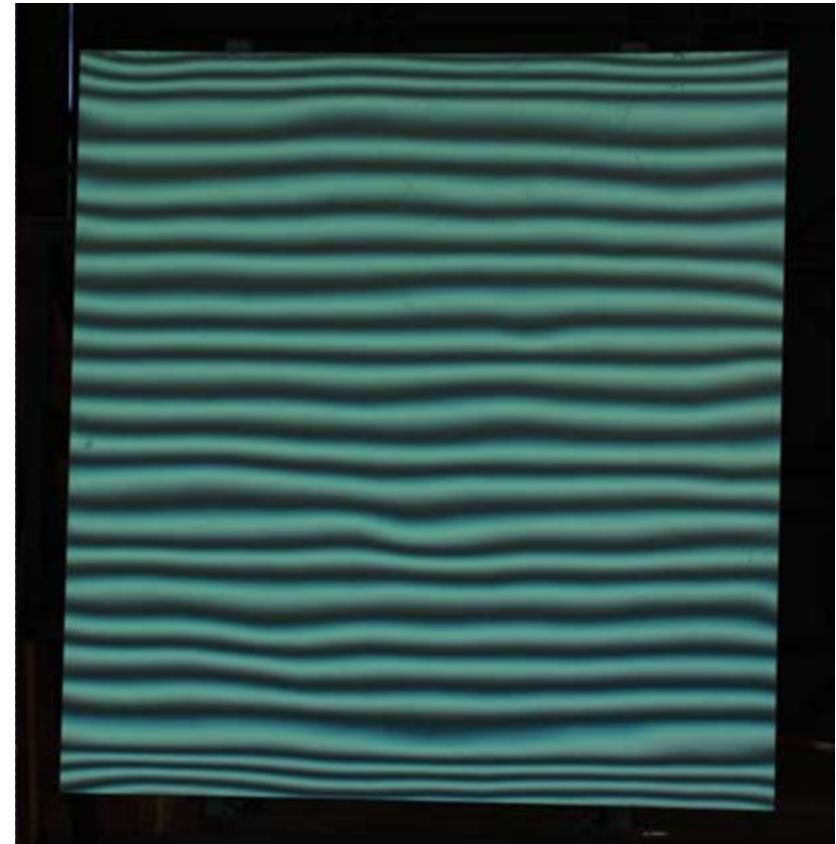
Deflectometry – Principle and Measurement Setup



Example

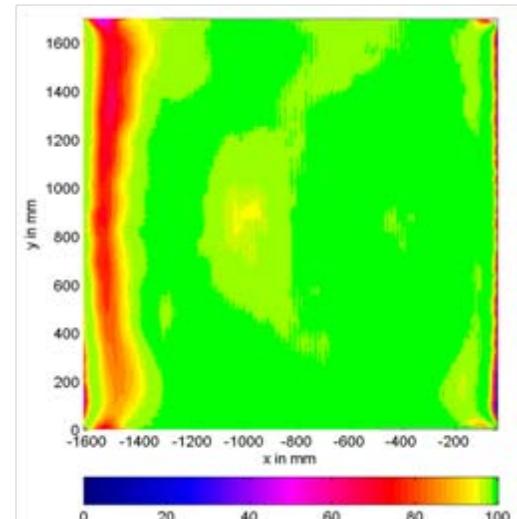
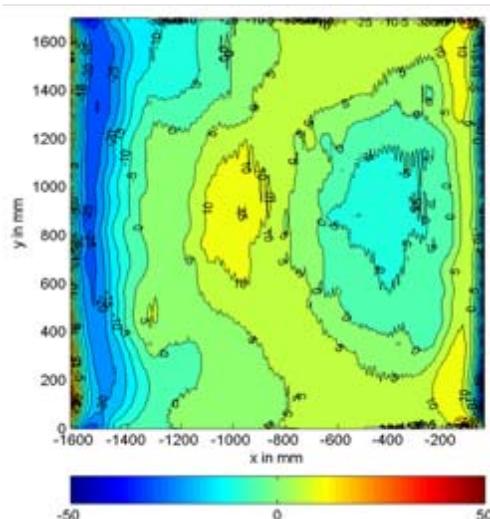
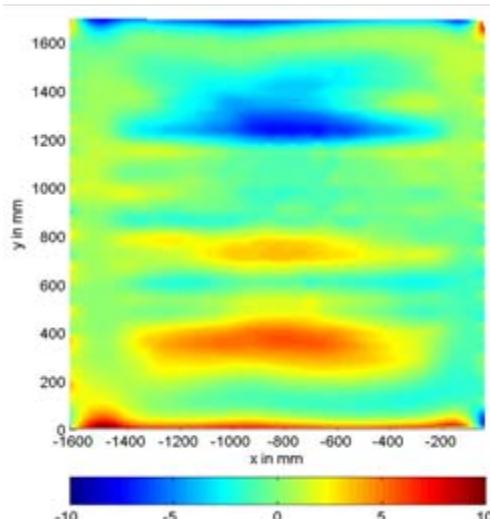
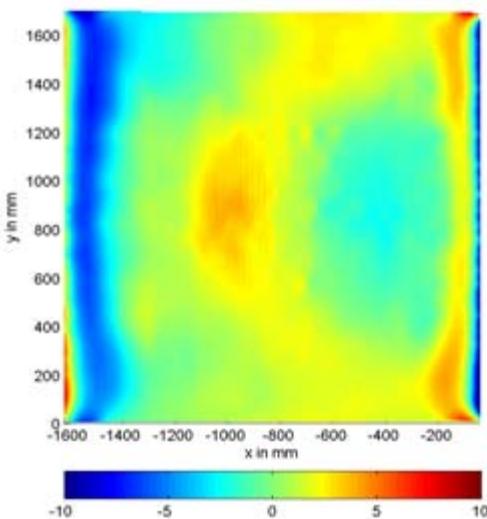


Pattern on screen

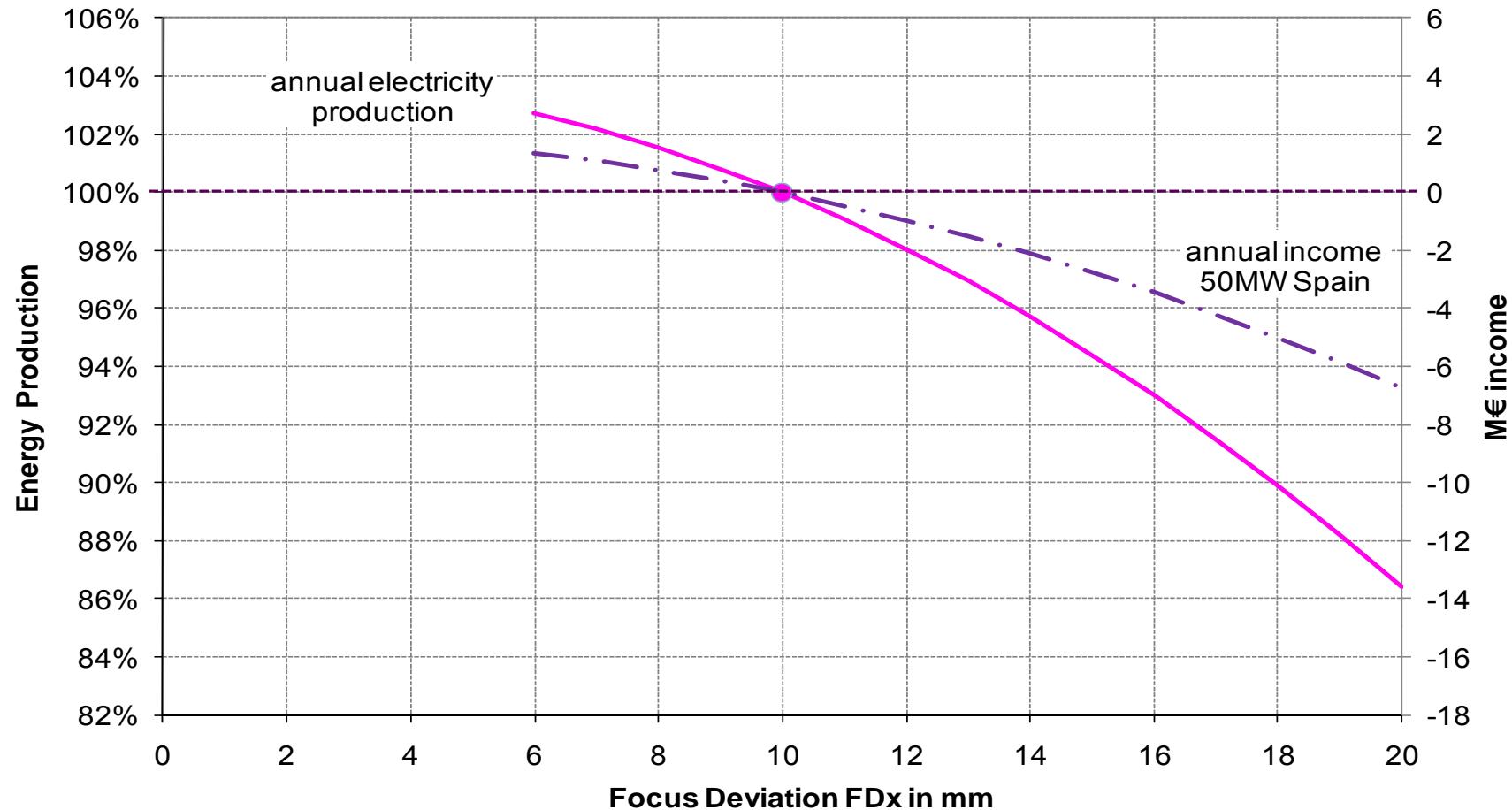


Pattern in seen in the mirror

Example: Facet for Parabolic Trough

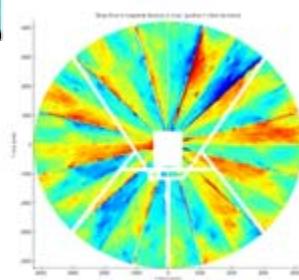


Influence of FDx on Energy Production and Annual Income – Andasol-type (50MW, storage, Spain)

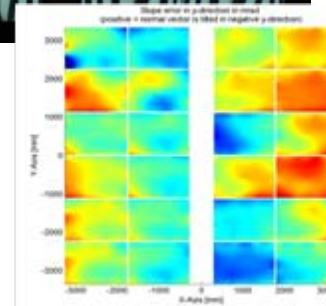
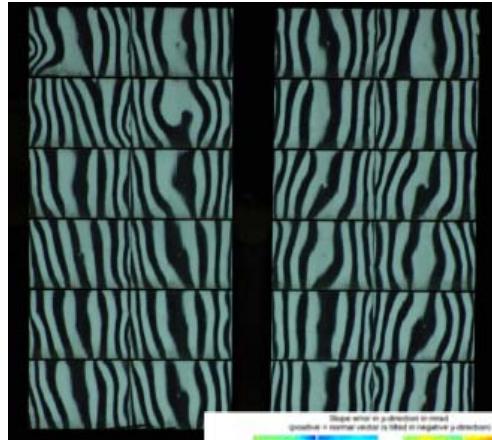


Deflectometry Flexible Application for Different Concentrator Types

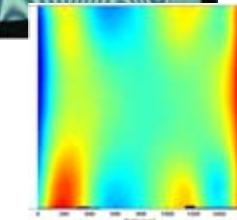
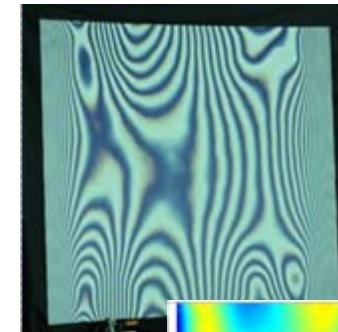
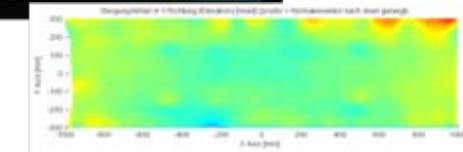
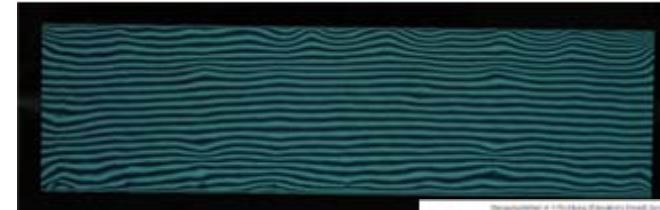
Dishes



Heliostats



Panels (Fresnel, Dishes, Parabolic Trough)

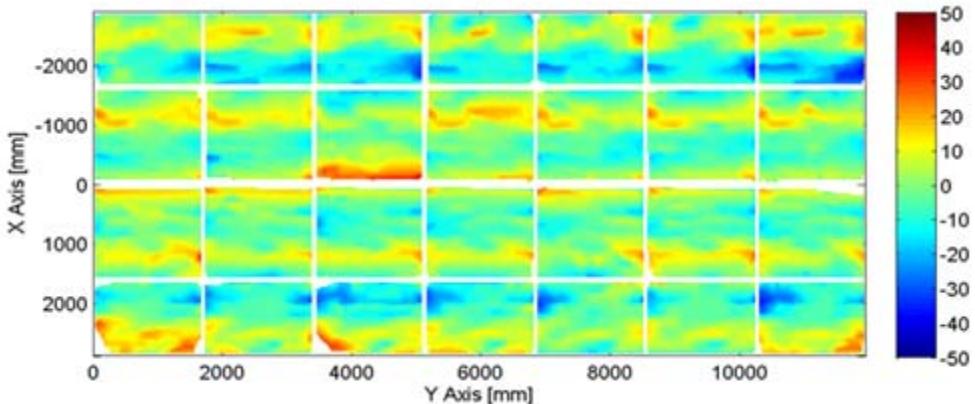
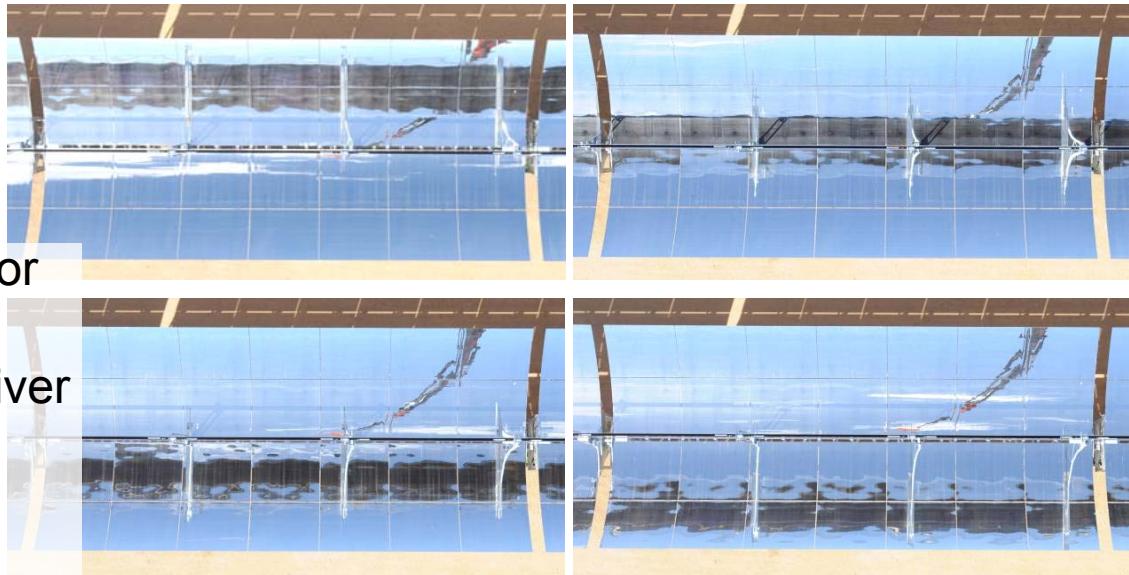


Deflectometry – Absorber Reflection Method

- Field measurement of collector shape quality
- Deflectometry using the receiver image

Deflectometry is developed at

- DLR (Spin-off CSP-Services)
- NREL (USA)
- Ciemat (Spain)
- ENEA (Italy)
- ...





Conclusion

- ☛ CSP uses **direct** sun light
- ☛ Concentrate and absorb to high temperature
 - ☛ 300-400 °C (classic trough), or even much more
- ☛ Use heat in conventional thermodynamic cycle (thermal power plant)
- ☛ Generate electricity
- ☛ Storage possible

Mirrors

- ☛ Thick glass mirror 2nd surface reflector is standard ($\rho \sim 94\%$)
- ☛ Future options: Thin glass, Aluminum, Polymer
- ☛ Criteria
 - ☛ Price
 - ☛ Longevity
 - ☛ Solar weighted direct reflectance
 - ☛ Shape accuracy

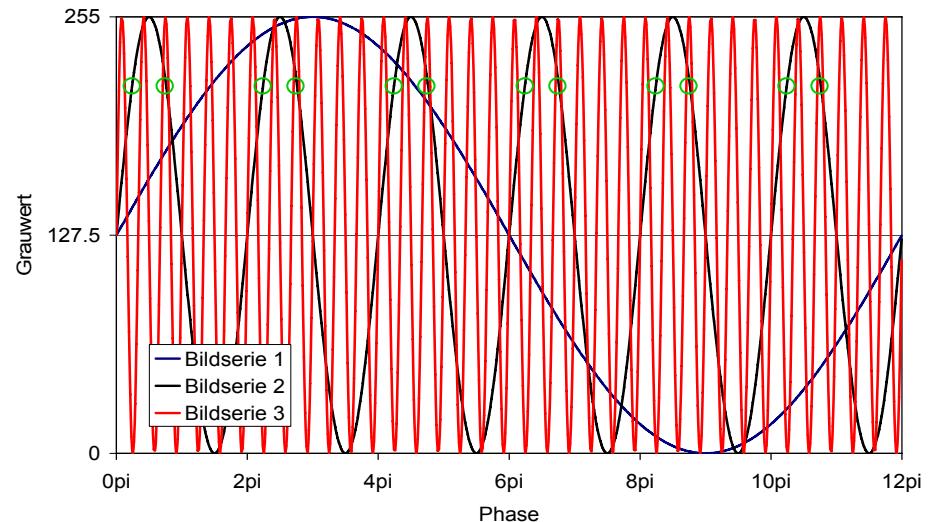
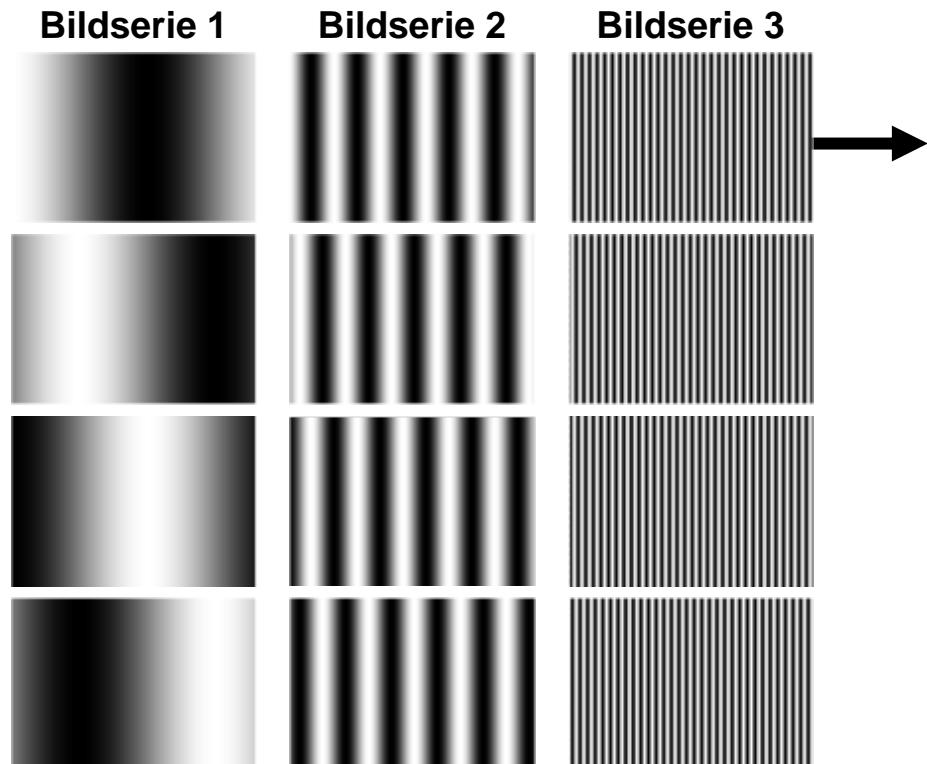


Thank you for your attention!



Ortskodierung der Projektionsfläche

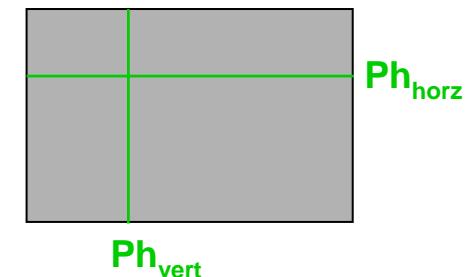
Hierarchisches Phasenshiftverfahren

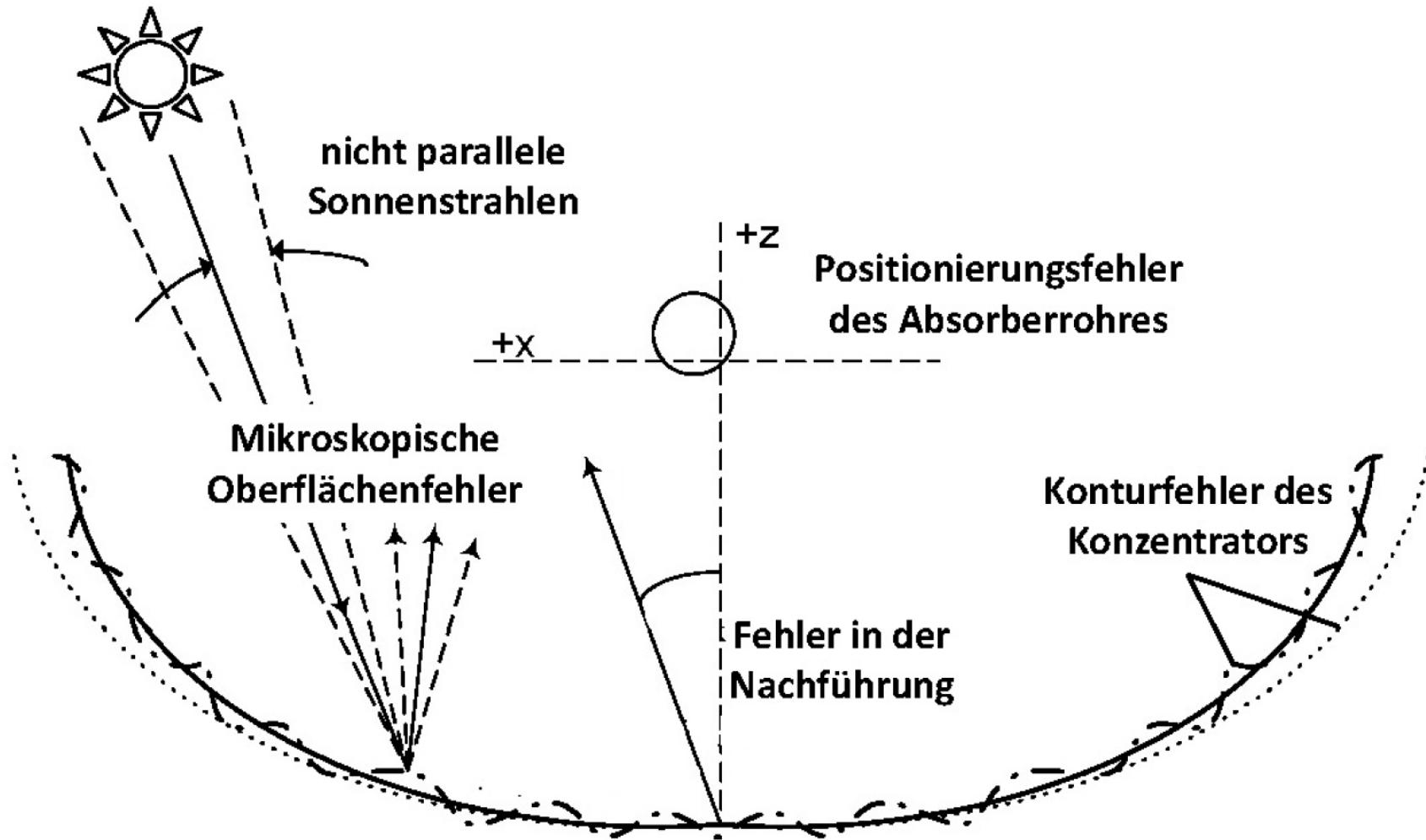


Horizontale Bildserien

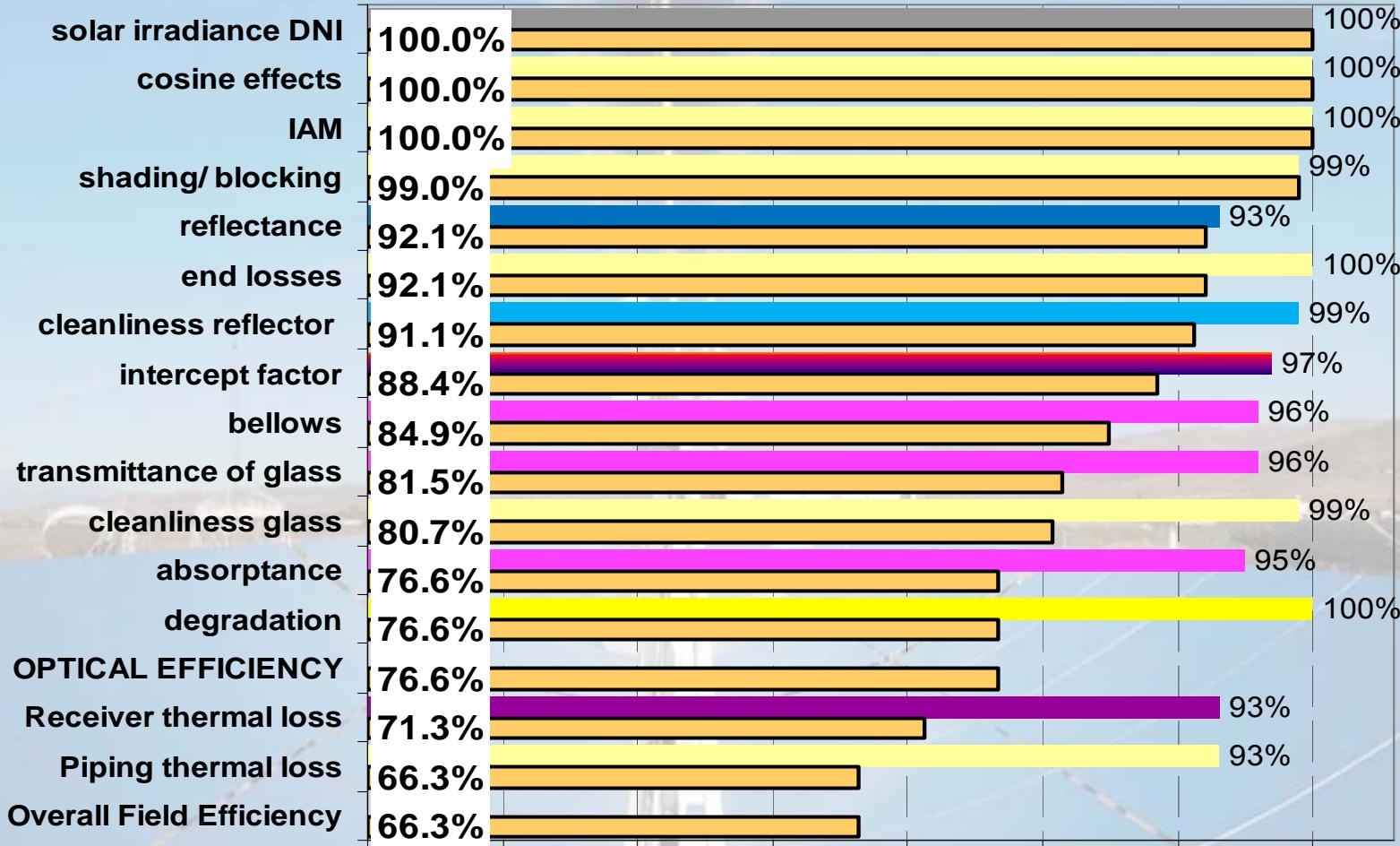


Eindeutige Ortskodierung





Peak efficiency of parabolic trough collector field current state of the art

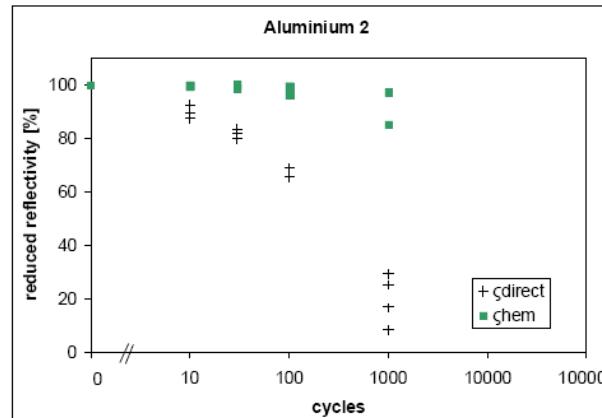
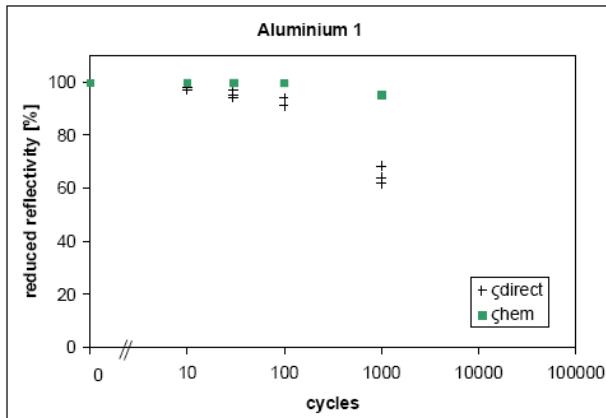
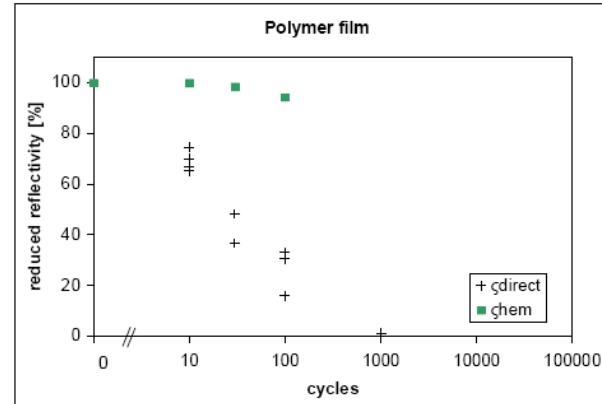
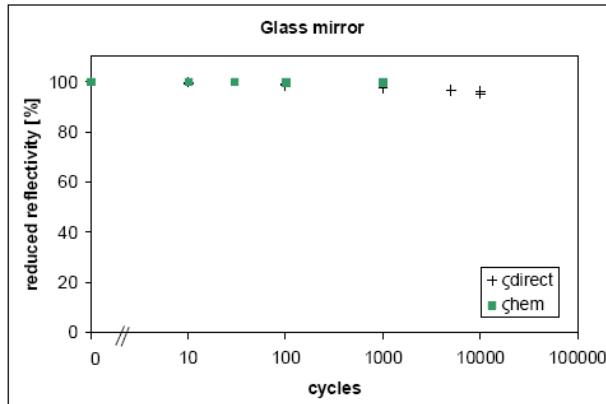


LOCALIZACIÓN DE CENTRALES SOLARES TERMOÉLECTRICAS EN ESPAÑA

PROTERMO
SOLAR



Abrasion Testing – Reduction in Reflectance



Meyen et al.: Optical Characterisation of Reflector Material for Concentrating Solar Power Technology,
Proceedings of Solar PACES Conference, Berlin, 2009

Solar Field Components

Example: 1 Andasol-3 plant 50 MW Spain

| | |
|---|---------------------------|
| ↗ Size | 1.5 x 1.3 km ² |
| ↗ Square meters effective collector aperture | 497 020 m ² |
| ↗ Nominal number of full load hours | 3755 h/a |
| ↗ Nominal output | 50 MW _e |
| ↗ Storage (60 % NaNO ₃ , 40 % KNO ₃) | 7.5 h |
| ↗ Turbine-Generator set | 1 |
| ↗ ground works | 1 200 000 m ³ |
| ↗ concrete | 50 000 m ³ |
| ↗ steel | 17 000 t |
| ↗ glass | 5 700 t |



Outline

- ☛ An Introduction to CSP Plants
 - ☛ Types
 - ☛ Market
 - ☛ Market perspectives
- ☛ Solar Mirrors
 - ☛ Types, Manufacturers, Concepts
 - ☛ Measurement - spectral
 - ☛ Measurement - shape
 - ☛ Ageing
- ☛ Conclusion



Rahmenbedingungen

- ↗ Donnerstag, 20.10.2011, 12:30-13:00
- ↗ Ziel: 25 min + 5 min Fragen



Themenvorschläge

- ↗ DESERTEC ist ein Szenario, ein Verein www.desertec.org und eine Industrie-Initiative www.dii-eumena.com
- ↗ Mediterranean solar plan
- ↗ schau auch hier mal rein <http://www.dw-world.de/dw/article/0,,5861222,00.html>
- ↗ CSP = concentrating solar power. Solar thermal power plants
- ↗ Large mirrors reflect the beam sunlight onto absorbers (receivers)
- ↗ Technology is commercial since SEGS plants California 1986ff.