Parabolic Trough Collector Overview

notes on a bit of history, development after Luz, and a recent surge in trough collector technology offerings

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Parabolic Trough Workshop 2007
at the
National Renewable Energy Laboratory, Golden CO

From then to now …

In the late 70's and early 80's Sandia and SERI funded and carried out parabolic trough technology and IPH project development

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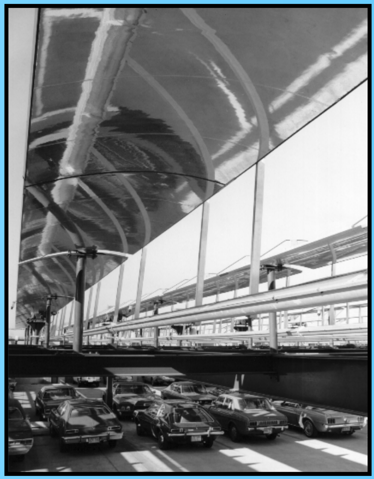
A US/Israeli company watched, listened, added their own ideas, and entered the solar IPH business in the U.S.

But the overhead was too high, and **Luz** seized an opportunity to develop a higher temperature trough for a 14 MWe project selling electricity to SCE.

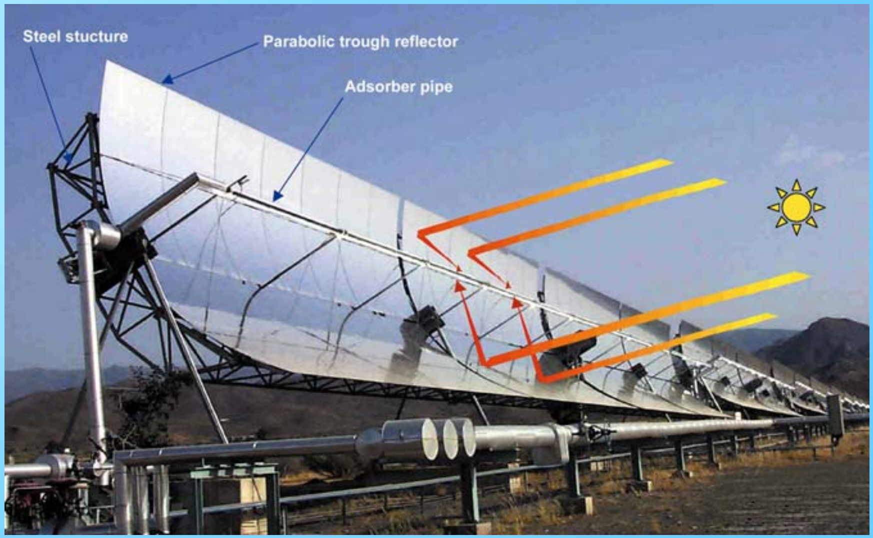
Honeywell Trough System 1978



Voilá … the SEGS plants were born!

After facing regulatory, financial and internal hurdles that resulted in failure of the SEGS X development, Luz went bankrupt in 1991.

From 1991 through much of the 90's, no new collector developments took place until the EuroTrough collector project was cost-shared by the EU and a group of European companies. During this period, Flabeg of Germany and Solel Solar Systems of Israel (rising from the ashes of Luz) supplied mirrors and receivers, respectively, to the operating SEGS plants. Only Solel was in a position at that time to supply a trough solar **field**, based on the LS-3 design developed by Luz. Lack of competition in commercial component and system supply was an important concern to developers, institutions and debt providers.



There were other influencing events during this period of no commercial development in CSP.

Key examples include …

- ✓ the EuroTrough project which began in 1998, cost-shared by a group of European companies and the EU
- ✓ a small but very influential workshop in Boulder in 1998, sponsored by NREL, to lay out a roadmap for parabolic trough development
- ✓ the open access to the very well operated plants at the Kramer Junction SEGS site (with five 30 MWe trough plants)
- ✓ the O&M cost reduction program at KJ, cost-shared between KJCOM and DOE (via Sandia)
- ✓ the growth and influence of SolarPACES internationally
- ✓ Sargent & Lundy positive CSP assessment in 2003

In a few short years, however, the situation has changed dramatically. As the trough project opportunities in Spain and the Southwest U.S. (in particular, in California) have increased, more companies are applying their expertise to develop commercial trough solar system designs.

At present, the list appears to be: (in random order)

- **Flagsol (part of Solar Millennium)**
- **Solel Solar Systems**
- **Acciona Solar Power (was Solargenix)**
- **Sener / ACS Cobra**
- **Solucar R&D (part of Abengoa)**
- **IST Solucar (part of Abengoa)**

The field experience and maturity of designs offered by these companies varies considerably, and must be carefully considered.

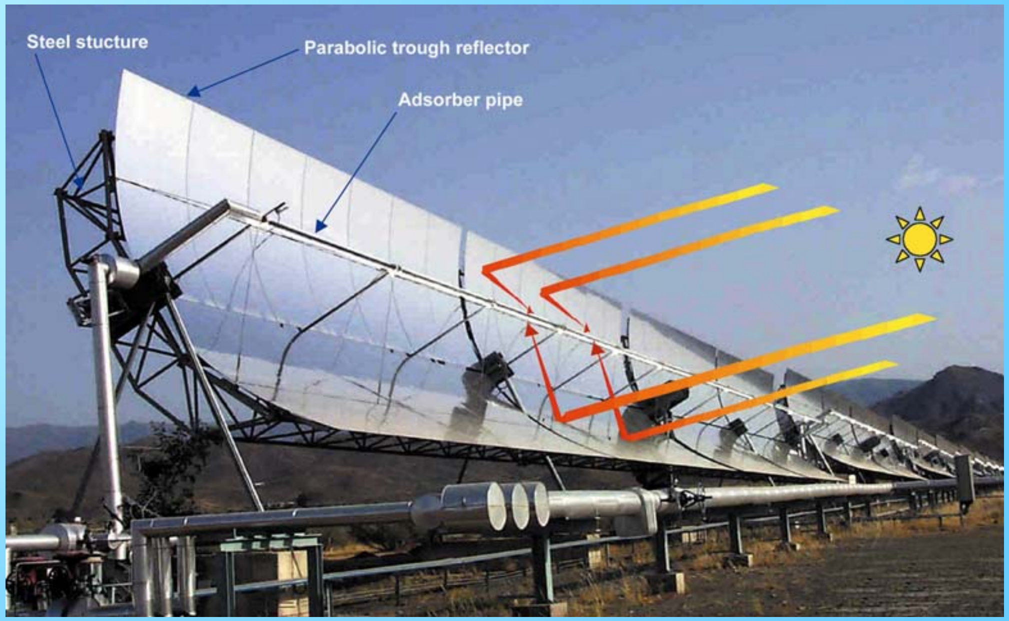
But an old adage applies … " the devil is in the details "

Collector designs …

Elements of a Parabolic Trough System

- Trough Collectors (single-axis tracking)
- Heat-Collection Elements
- Reflectors
- Drives, controls, pylons

- Heat-transfer oil
- Oil-to-water Steam Generator
- Oil-to-salt Thermal Storage
- Conventional steam-Rankine cycle power block



Courtesy of Flagsol GmbH

Some Design Goals of a PT Collector to Achieve High Performance, Low Cost, Reliability and Durability

- High optical and tracking accuracy
- Low heat losses
- Manufacturing simplicity
- Reduced weight and cost
- Increased torsional and bending stiffness under wind loads
- Reduced number of parts
- Corrosion resistance
- More compact transport methods
- Reduced field erection costs, w/o loss of optical accuracy
- Increased aperture area per SCA (reduced drive, control and power requirements per unit reflector area)

Collector	**Flagsol** **SKAL-ET 150**
Structure	**Torque box design-galvanized steel**
Wind load design basis	31.5 m/s
Aperture width	5.77m
Focal length	1.71m
Length per collector module	12m
Length per SCA	148.5m
Location of C.G.	3.5m
Rim angle	80

Geometric Concentration	82
Reflector	glass mirror
Bearing type	--
Interconnect	--
Drive	hydraulic
HCE type	evac. tube
Sun sensor	Flagsol
Foundations	pile
SCAs/loop	4
Control system	Flagsol
Erection method	jig

Summary	
Aperture area	817.5
Weight/m^2	~ 33 kg/m^2
Peak optical η	80 %
(Reference)	FPL SEGS V
Field experience	Loop at KJ SEGS V 4 yr

Collector	**SENER**
Structure	**Torque tube + stamped steel cantilever mirror support arms**
Wind load design basis	33 m/s
Aperture width	5.76m
Focal length	1.70
Length per collector module	12m
Length per SCA	150m
Location of C.G.	--
Rim angle	--

Geometric Concentration	~80
Reflector	glass mirror
Bearing type	--
Interconnect	rotating joint
Drive	hydraulic
HCE type	evac. tube
Sun sensor	--
Foundations	site specific
SCAs/loop	4
Control system	open loop
Erection method	jig

Summary	
Aperture area	>800m^2
Weight/m^2	-- kg/m^2
Peak optical η	-- %
(Reference)	--
Field experience	PSA

Collector	**IST Solucar PT-2**
Structure	- -
Wind load design basis	35.8 m/s
Aperture width	4.4m
Focal length	1.7m
Length per collector module	12m
Length per SCA	148.5m
Location of C.G.	near bearing
Rim angle	72

Geometric Concentration	~ 63
Reflector	Polished aluminum or silver film on aluminum
Bearing type	pillow block
Interconnect	ball joint
Drive	linear actuator or hydraulic
HCE type	evac. tube
Sun sensor	flux line
Foundations	concrete caissons
SCAs/loop	4 for IPH
Control system	feedback
Erection method	On site factory assembly

Summary	
Aperture area	430 m^2 per drive
Weight	~ 17 kg/m^2
Peak optical η	75 %
(Reference)	estimate
Field experience	--

Collector	**Acciona Solar Power SGX 2**
Structure	**Recycled aluminum or steel struts and geo hubs***
Wind load design basis	~33 m/s
Aperture width	5.77m
Focal length	--
Length per collector module	12m
Length per SCA	100-150m
Location of C.G.	--
Rim angle	--

* Increased rigidity via interlinking; no site cutting or welding; shipping requirements simplified

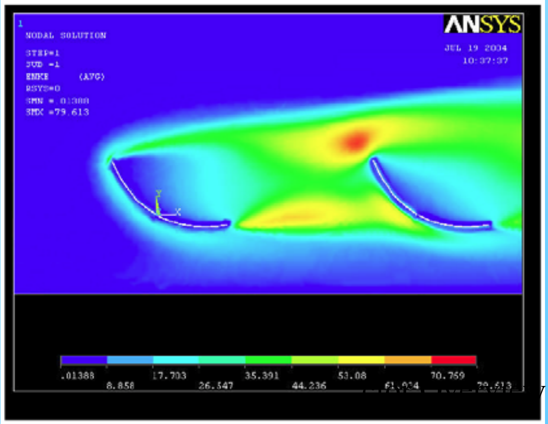
Geometric Concentration	82
Reflector	glass mirror
Bearing type	--
Interconnect	ball joints
Drive	hydraulic
HCE type	evac. tube
Sun sensor	Acciona
Foundations	--
SCAs/loop	4
Control system	Acciona
Erection method	no jig needed for assembly

Summary	
Aperture area	470 m^2/SCA
Weight/m^2	~ 22 kg/m^2
Peak optical η	~ 77 %
(Reference)	Sandia
Field experience	1 MW AZ 64 MW NV

Collector	**ENEA** Lab design for molten salt HTF
Structure	Tourqe tube with precise reflector support arms. Material: Cor-Ten steel+ zinc-coated carbon steel
Wind load design basis	~ 33 m/s
Aperture width	5.76 m
Focal length	~ 1.8 m
Module length	12.5 m
Length per SCA	100 m

Geometric Concentration	~75-80
Reflector	Exploring several options
Bearing type	--
Interconnect	flex hoses
Drive	hydraulic
HCE type	evac.
Sun sensor	--
Foundations	--
SCAs/loop	--
Control system	ENEA for molten salt
Erection method	simple assembly

Summary	
Aperture area	~ 540
Weight/m^2	- -
Peak optical η	~ 78%
(Reference)	ENEA
Field experience	ENEA test loop 2 yr



CFD Analysis

Wind Tunnel test

Others

- Solel and Solucar R&D provided only top-level information
- Solel Solar Systems - Solel 6
  - Advanced design based on LS-3 dimensions
  - Optical efficiency 80%
  - Test loop at Sde Boker, Israel
  - Will be used for joint projects of Sacyr/Solel
  - Structural approach changed to a torque tube design
- Solucar R&D (Abengoa)
  - Advanced design based on EuroTrough concept
  - Aperture, mirrors and receivers same as EuroTrough
  - Key goals of new design are to decrease structure weight and reduce time for field assembly

Collector pix …

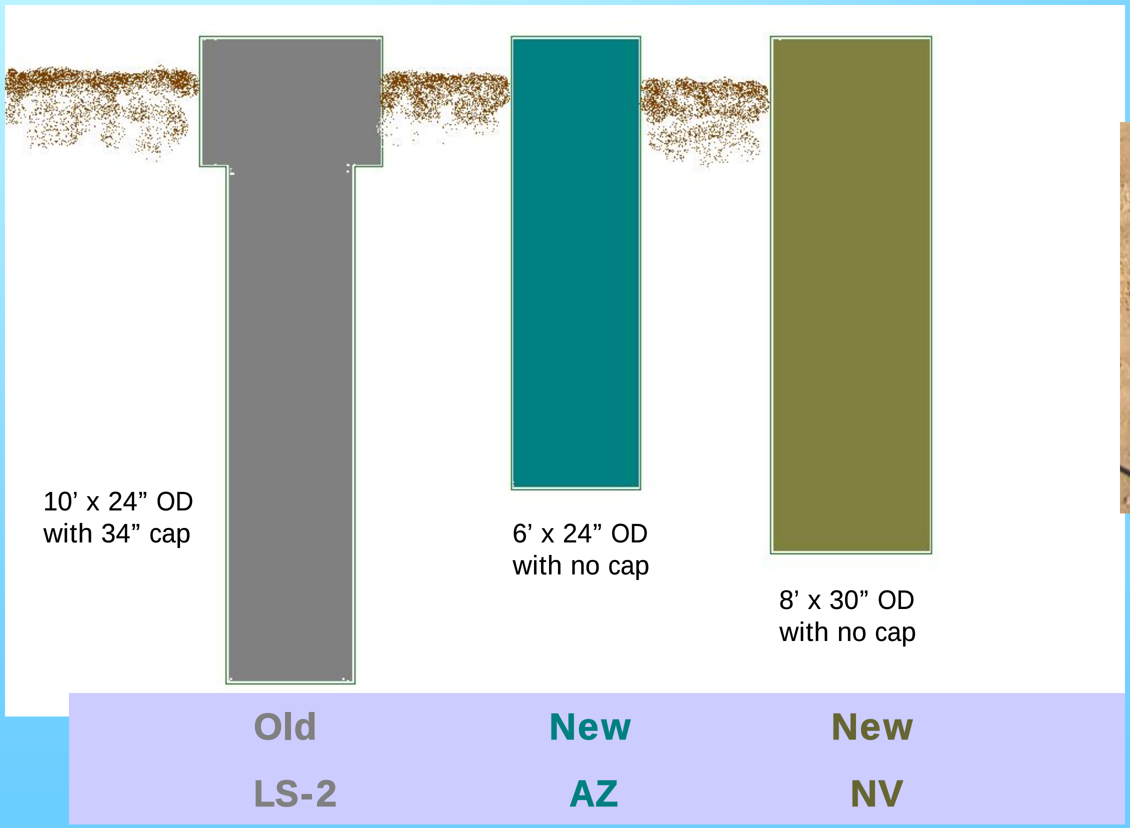
Flagsol
SKAL-ET150

Pictures from the test loop at the Kramer Junction SEGS site

Steel-Reinforced Drilled Pier Foundations

Objective: Reduce Costs while Designing for Peak Wind Loads

Consider Two Project Locations (Nevada and Arizona)



Acciona hydraulic drive at 1 MW APS project

ENEA: new system under test

Solel 6 collector in loop test at Sde Boker

Reflectors and Receivers …

Reflectors

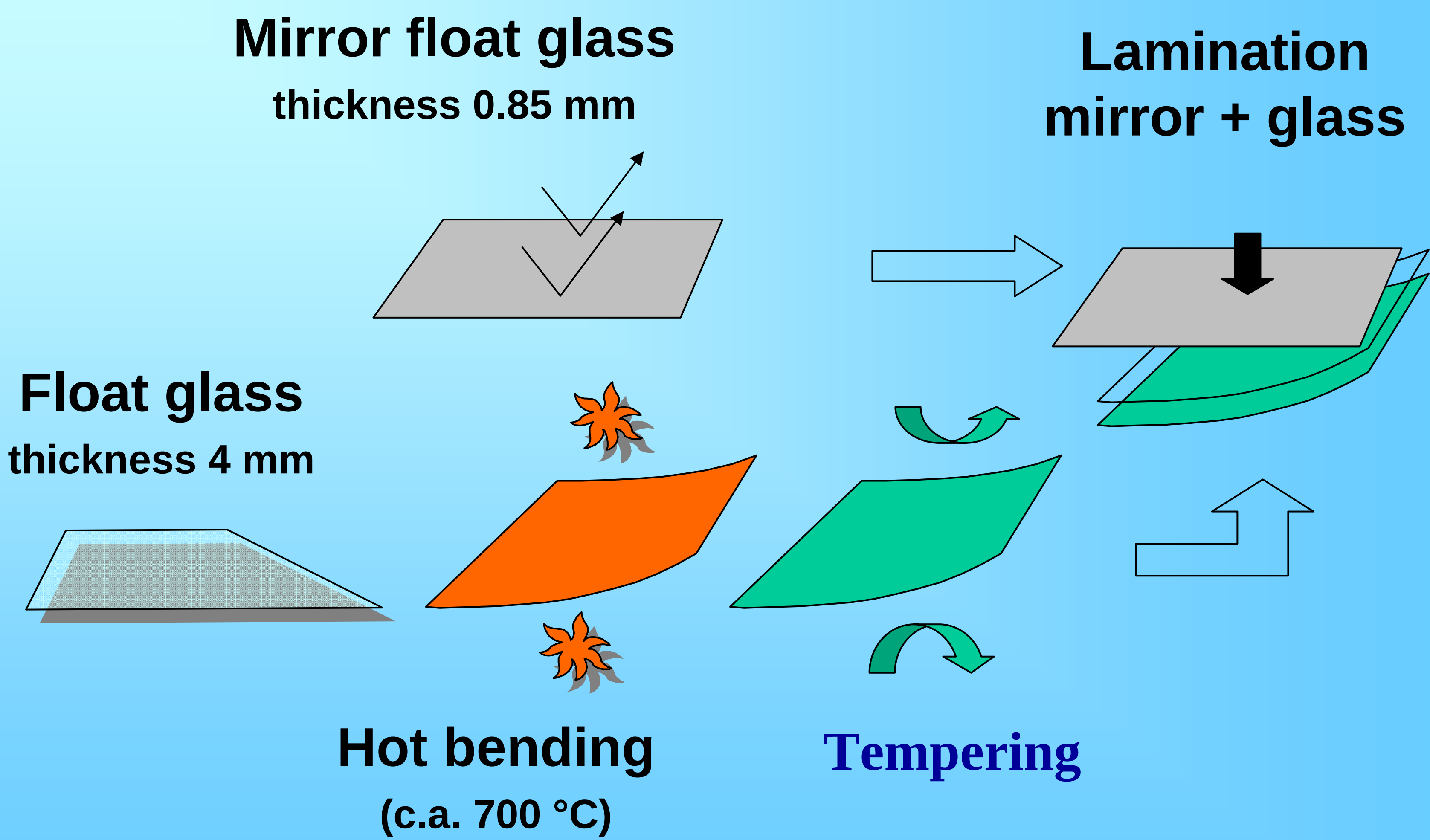
Flabeg Glass Mirrors

- Most current designs use Flabeg glass mirrors, and this is the only reflector used in the current commercial trough projects (SEGS/NS1/APS/AndaSol-1)
- 4mm glass mirrors have an initial hemispherical reflectivity of 93.5%
- Flabeg states that 98% of the reflected radiation fall on a 70mm diameter receiver
- Field durability of optical properties and configuration has been excellent at SEGS plants
- Other glass/mirror manufacturers evaluating market

Some other options

- Considerable R&D has been and is being conducted on options using silvered or aluminized films, thin glass, and front-surface mirrored glass
- ENEA has been systematically evaluating several reflector options
- ReflecTech offers silverized polymer film on a polymer substrate laminated to Al
- Alanod (Germany) offers a alumized polished aluminum reflector with a nanocomposite oxide protective layer

ENEA: one of several reflector options
Reflecting facets: laminated glass



ReflecTech Silvered Film

- High Solar Reflectance
  - ~ 93.5% Hemispherical Reflectance
- Testing on Outdoor Weatherability
  - Ongoing NREL and Independent Lab Testing
- Low Production Costs
  - Commercially-Available Materials
  - No Capital Investment in New Equipment
- Roll Widths Sufficient for Large-Scale Solar
  - 60 inch wide rolls and smaller

Prototypes at Kramer Junction SEGS: 2004

Alanod Polished Aluminum

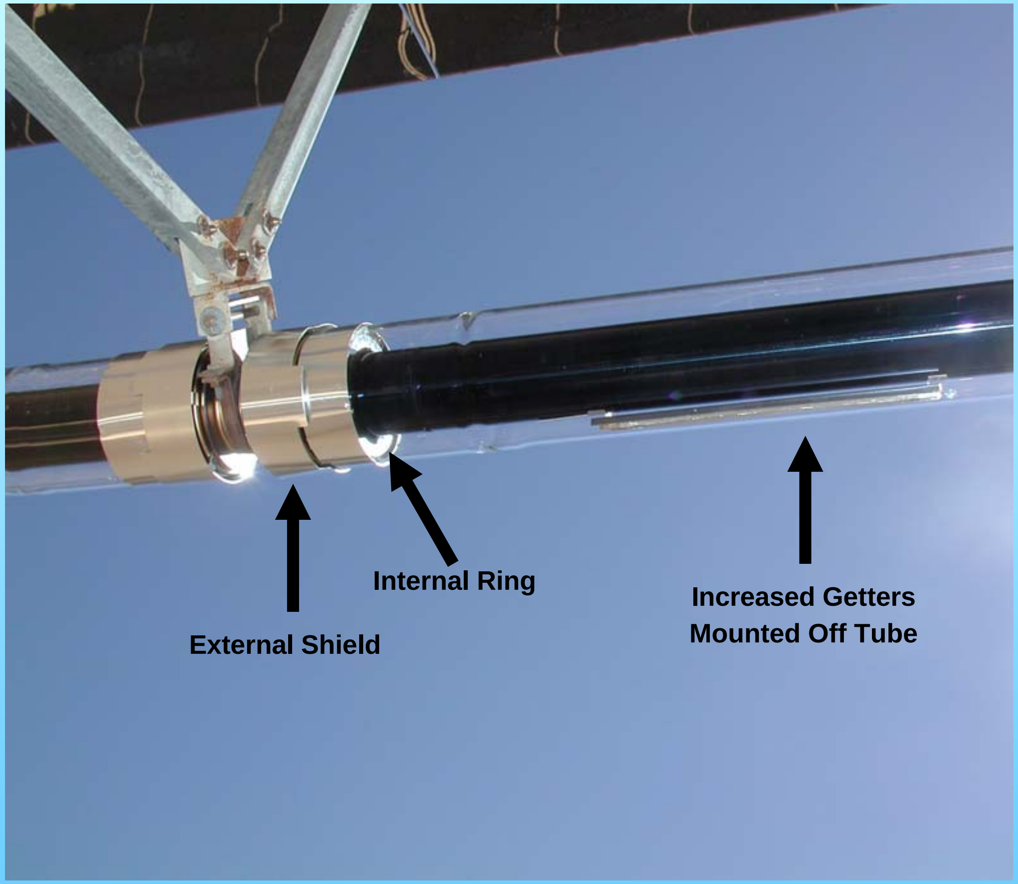
- High Solar Reflectance
  - 91.5% Hemispherical Reflectance
- Testing on Outdoor Weatherability
  - Ongoing NREL testing; no change after 1 year
- Low Production Costs
  - Purchased industrial roll-coater for production

Thin Glass Mirrors (Naugatuck)

- High Solar Reflectance
  - 95.5-96% Hemispherical Reflectance
- Testing on Outdoor Weatherability
  - Outdoor and accelerated NREL testing
- Low Production Costs
  - Commercially available materials
  - Surplus capacity in industry

Receivers

New Solel UVAC HCE



- **Improved Reliability**
  - Improved external bellows and glass-to-metal seal shielding
  - Added internal ring for glass-to-metal seal protection
  - Very low failure on latest generation (<<1%)
- **Improved Vacuum Lifetime**
  - Increased amount of getters for absorbing hydrogen
  - Improved getter mounting to keep getters cool to increase hydrogen absorption capacity
- **Improved Selective Coating**
  - New cermet coating that does not include Molybdenum (eliminates Fluorescent tube problem).
  - Higher absorption
  - Lower emittance

New Schott PTR HCE

- **Improved Reliability**
  - Improved match between glass and metal coefficients of thermal expansion
  - 100% testing of glass-to-metal seal
  - No glass-to-metal seal failures in field testing to date
- **Improved Performance**
  - New bellows configuration that compresses when tube is hot (~2% benefit)
  - Improved getter mounting to keep getters cool to increase hydrogen absorption capacity
  - More durable anti-reflective coating on glass
- **Selective Coating**
  - Similar to Luz (with Molybdenum)

New Schott Bellows Design

Schott Receivers at APS 1-MWe Trough Plant

SCHOTT PTR 70

- Development 2002 - 2005
- Market introduction in 2006

AR-coated cover tube with high transmittance
solar transmittance ≥ 96%
high abrasion resistance

Fail-safe glass-to-metal seal
new material combination with matched coefficients of thermal expansion

Steel tube absorber with highly selective coating
solar absorptance ≥ 95%
emittance ≤ 14% @400°C
High durability

Design with reduced bellow length
active length > 96%

Vacuum insulation
pressure < 10^{-3} mbar
maintained by new getter assemby

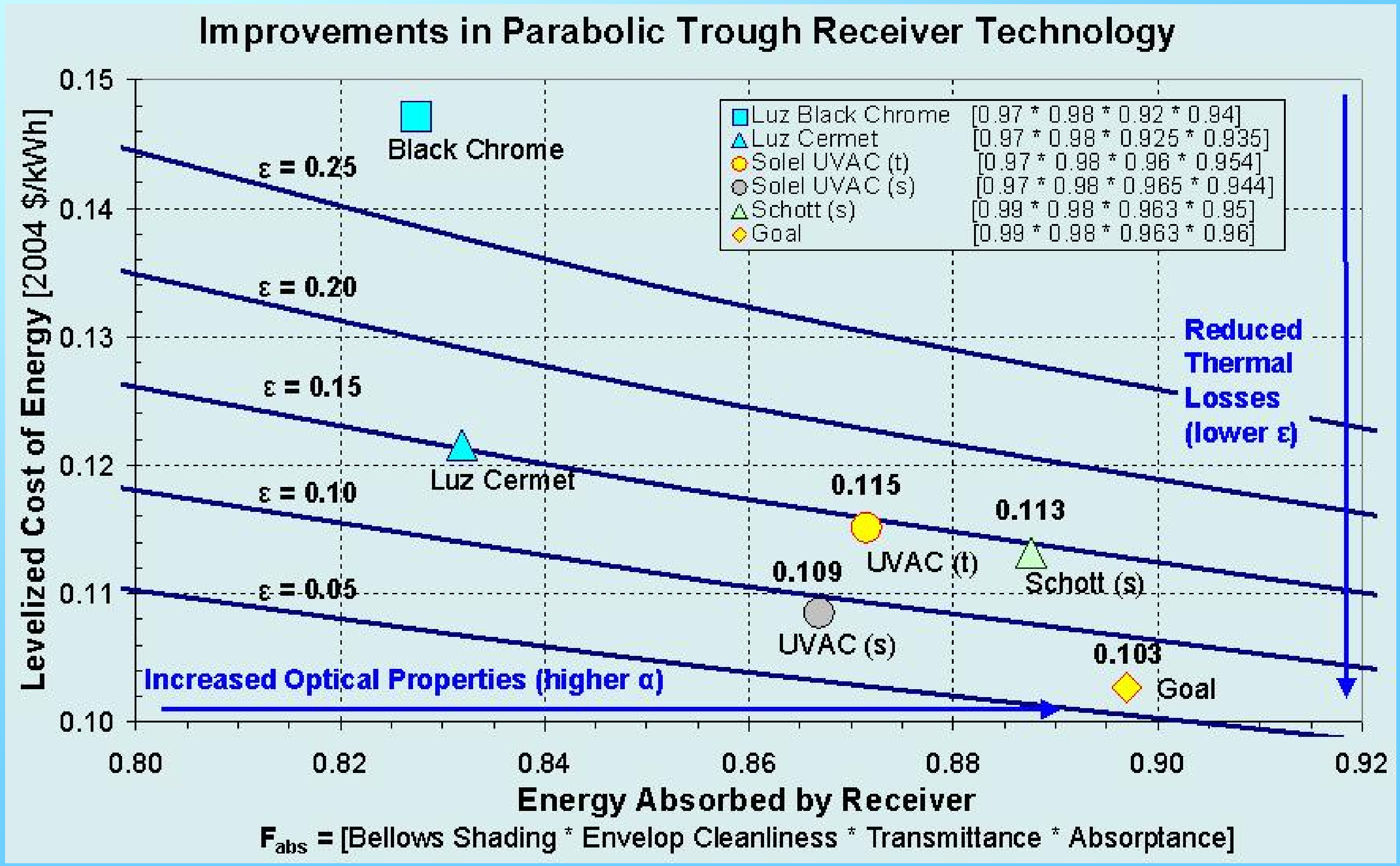
New SOLEL 6 Model

Smaller bellows leading to Increased area for absorption and higher efficiency

ENEA

- In pursuit of a high temperature receiver that can take advantage of the use of molten salt as the field HTF
- Working within ENEA and with Schott to achieve an optical coating with excellent characteristics capable of operating as high as 550°C

Selective Coatings Developments



Optical Characterization

- Optical characterization of the focusing of trough collectors is critically important to in all steps of collector implementation
- A session will be held tomorrow on this topic led by Eckhard Lüpfert
- Optical characterization is important in all steps of trough development: design, manufacturing, maintenance and operation

Observations

- The dimensions and configuration of these collectors are dictated by:
  - the basic configuration of a parabolic linear concentrating solar thermal collector
  - The limited selection in reflectors and receivers for commercial application
  - The nature of the forces imposed on such a collector (dictated by wind, not dead weight)
- As a result, there are clearly many similarities between them.
- The structural approach remains an area of difference:
  space frame vs. torque tube.
- The remaining sub-systems, e.g., drive, controls, torque transfer mechanism, bearings, are important for function and reliability, and part of the remaining “details”.
- The SEGS experience has been crucial and invaluable as a basis to what is happening today … Luz deserves great credit for its contribution to jump-starting this technology.

Thanks for your attention …

Aerial photo - Feb07 - 64 MWe Nevada Solar One
Parabolic Trough Solar Power Plant
Courtesy of Acciona Solar Power (Developer)

Backup …

Points to make:
-- no endorsements are intended in this presentation
-- being a workshop, I intend to point out designers or company representatives at various times so you can see who is behind the work noted here, and who to question after this overview to get more detailed information
-- mention KJC O&M cost reduction program in US, and 1999 trough roadmap meeting sponsored by NREL and Mr. Price.

Approx. material costs (NREL)

Type	$/ft2
Polished aluminum	2.50
Thick mirrored glass	4?
Thin mirrored glass	2.25
Silverized polymer film on Al	≤1.5

Support structure? Durability?