RAISELIFE

Raising the Lifetime of Functional Materials for Concentrated Solar Power

SolarPACES conference 2020

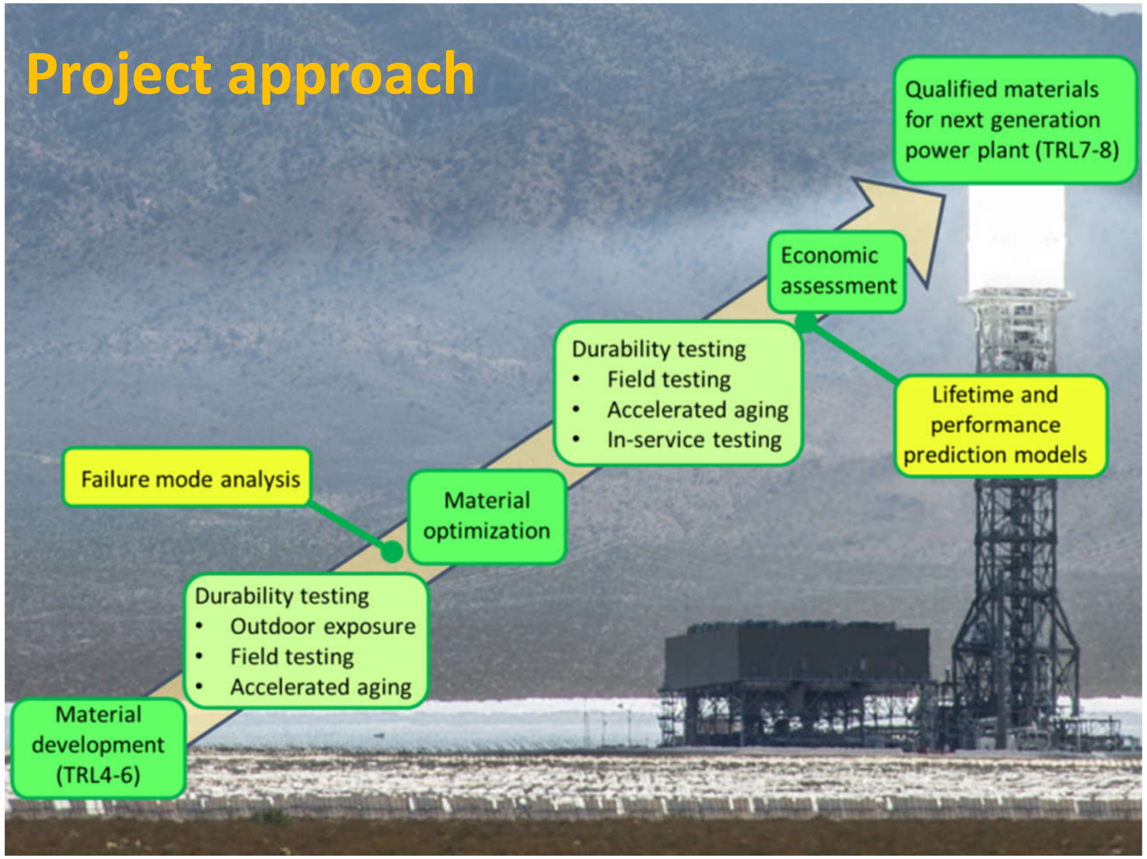
Florian Sutter (DLR) and RAISELIFE consortium

Project facts

Funded by: EU H2020 program,
Call: NMP-16-2016 Nanotechnologies, Advanced Materials and Production

Duration: 48 months
Start date: 01/04/2016
End date: 31/03/2020

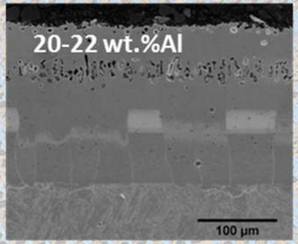
Budget:
Total cost: 10.5 M€
EU contribution: 9.3 M€

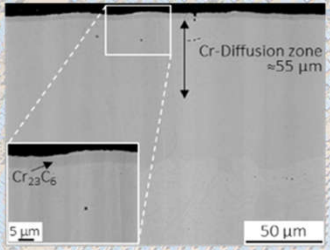


Coating and material developments in RAISELIFE

Molten salt corrosion protective coating

Reference: Inconel617 or Haynes230 (receiver), 347H (hot tank), Corrosion rate ~10µm/a, T=565°C, 7500€/ton





INTA DECHEMA

Secondary mirror

Reference: Silver mirrors with active cooling, T=80ºC

PECVD	HIPIMS
Barrier layer 2	Barrier layer 2
Adhesion Layer 2	Adhesion Layer 2
Silver Mirror	Silver Mirror
Adhesion Layer 1	Adhesion Layer 1
Barrier layer 1	Barrier layer 1
Steel substrate (1.4301)	Steel substrate (1.4301)

Fraunhofer

Absorber coating

Reference: Pyromark 2500

α_s = 97 %, $\varepsilon_{750°C}$= 82%

$\Delta\alpha_s$ = 2 %-p/a, T_{skin} ≈ 750°C

		AR-layer	
		Cermet	
Inorganic paint	Inorganic paint	Barrier layer	Slurry coating
Primer layer	Slurry aluminide	IR reflector layer	Cr-diffusion coating (~55µm)
		Adhesion layer	
T91 / VM12 / Inc-617 / H230	T91 / VM12 / Inc-617	T91 / VM12 / Inc-617 (polished)	T91 / VM12 / Inc-617
BrightSource	INTA BrightSource	Fraunhofer	DECHEMA

vallourec

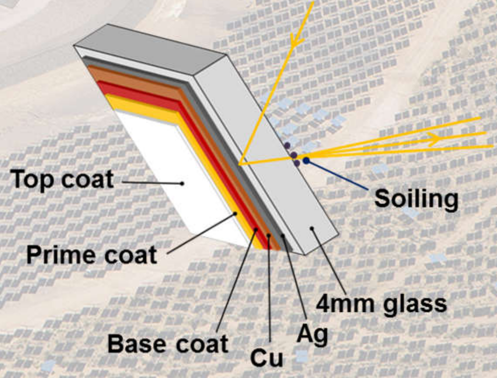
Reflector coatings

Reference: 3 back coatings, no anti-soiling-coating

Mirror cost: ~12 €/m²

Reflectance: $\rho_{s,\varphi}$ = 94.5 %

Degradation: $\Delta\rho_{s,\varphi}$ = 0.5 %-p/a in C2

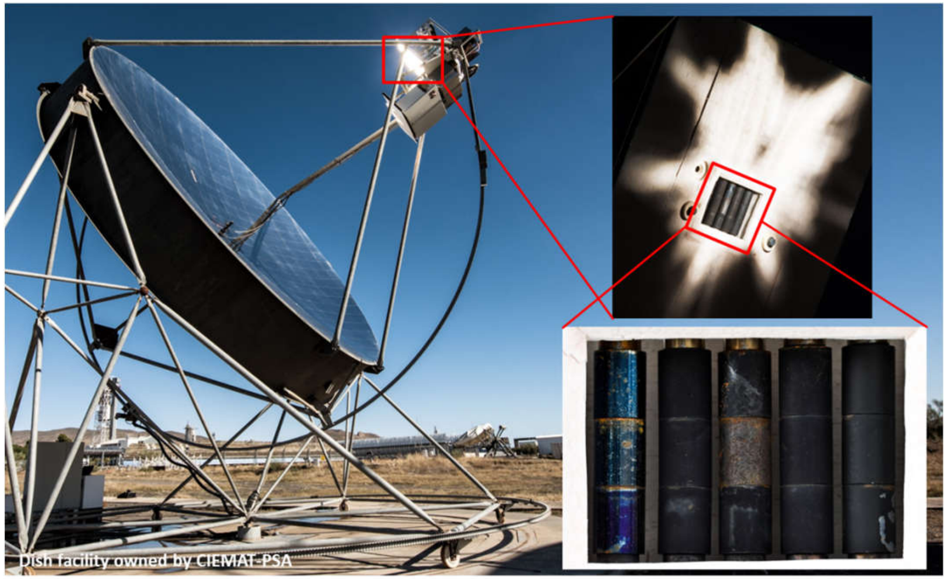


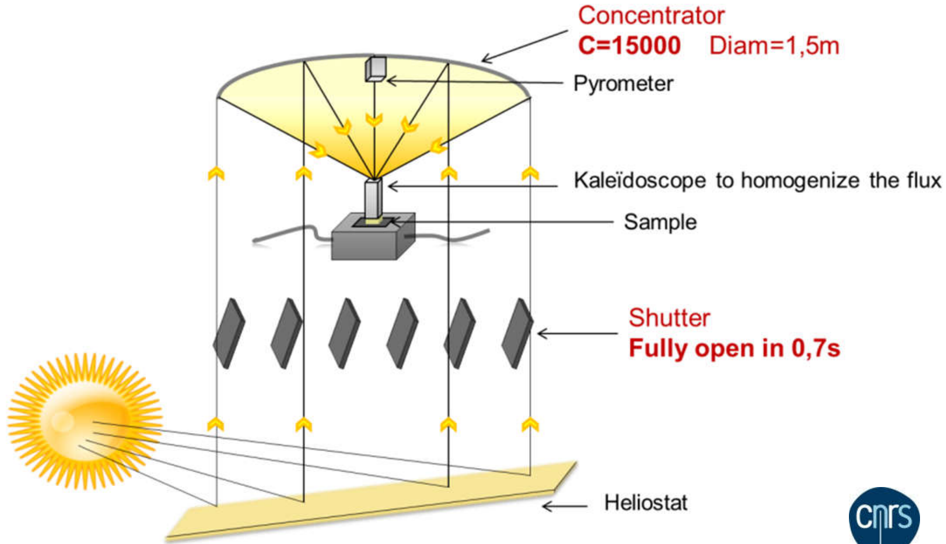
AGC FLABEG THE HEBREW UNIVERSITY OF JERUSALEM

- 4 low-cost back coatings
- 1 lead-free back coating (Flabeg)
- 6 anti-soiling coatings

[Image:Ivanpah, BrightSource]

Testing of new absorber coatings





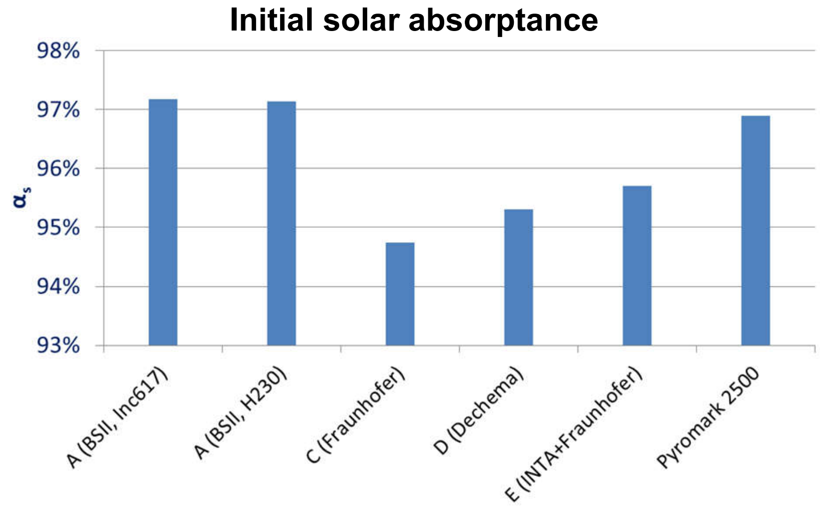
100 “slow” cycles: 200 - 650/750ºC, 30 K/min, 350 kW/m², 1h, combined with 1000h isothermal pre-oxidation and 120h of condensation

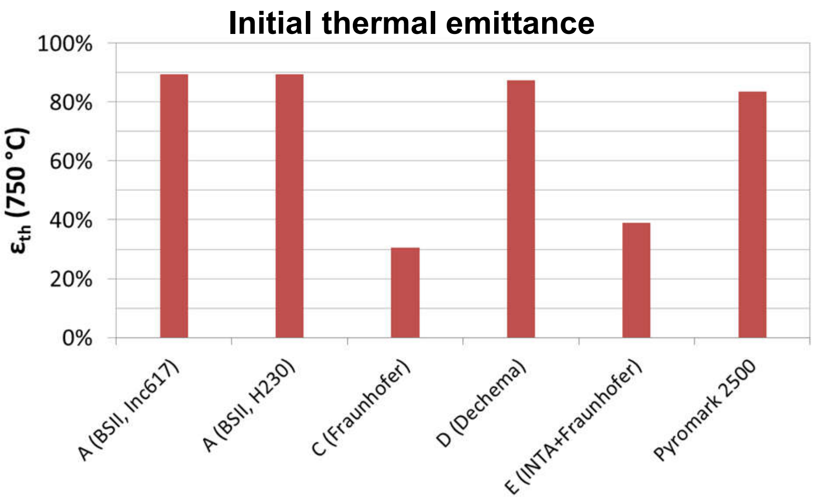
50 “fast” cycles: 400 - 650/750ºC, 300 K/min, 700 kW/m², 20min

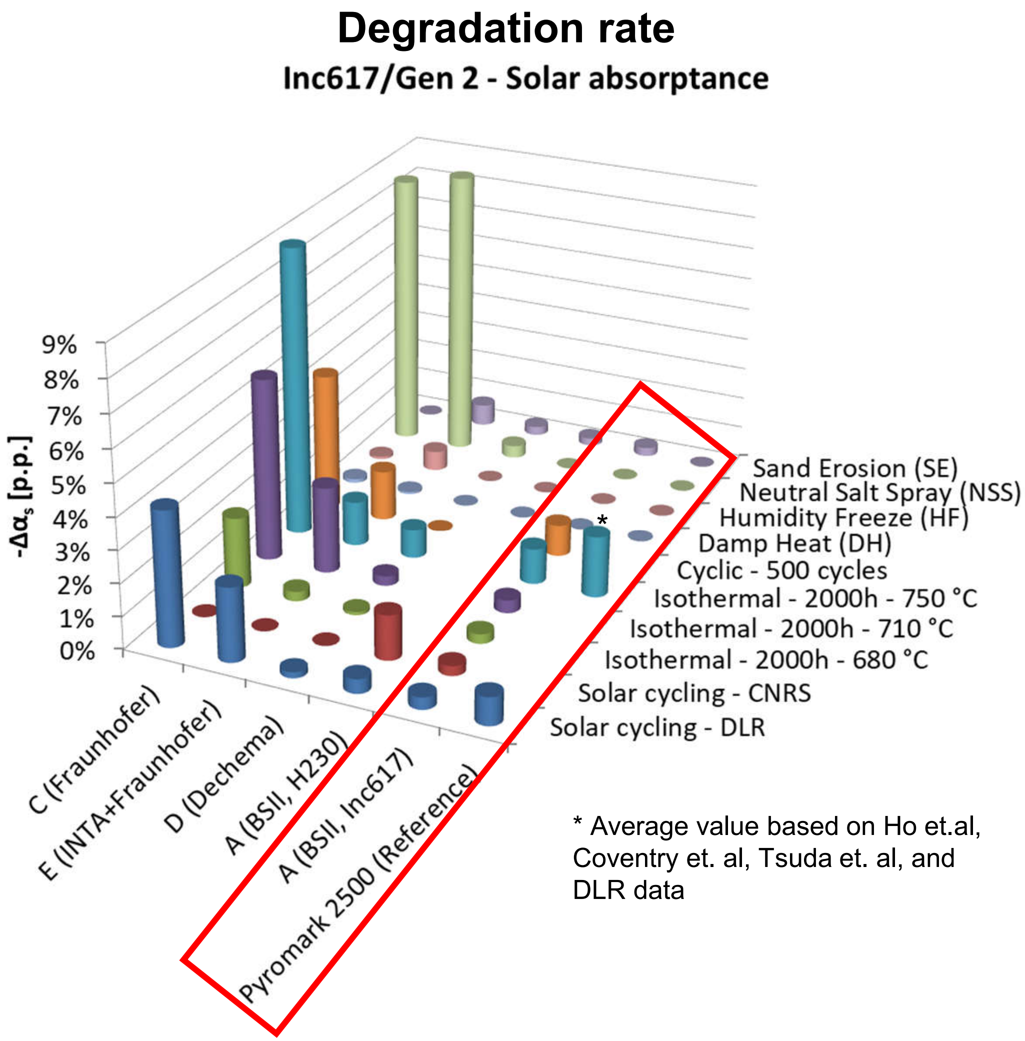
Lab testing:

- Climate chambers: Salt Spray, Humidity Freeze, Damp Heat, Sand Erosion
- Isothermal: 3 temperature levels, up to 4000h
- Cyclic furnace: up to 1000 cycles

Performance of new absorber coatings







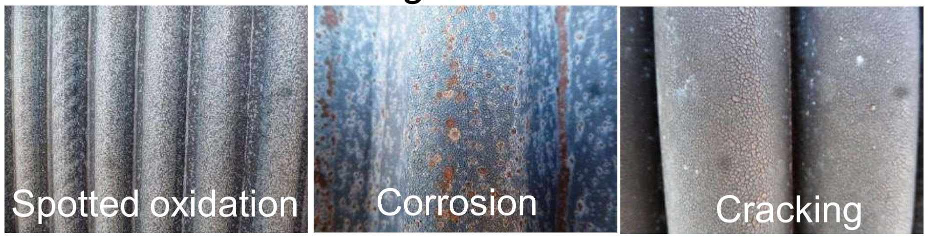
* Average value based on Ho et.al, Coventry et. al, Tsuda et. al, and DLR data

BSII coating tested in RAISELIFE will be employed in DEWA solar tower in Dubai
Lifetime of 15 years expected (7 years for T91 substrate of steam receivers)

Absorber coatings O&M

- Ivanpah: after 7 years of operation (+ 2 years construction) **no major failures**, only local repairs of BSII coating

Common local coating failure

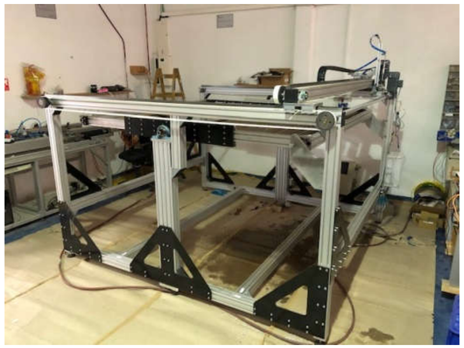


- On-tower recoating is challenging: cleaning and surface preparation, on-tower painting, complicated solar curing profile, etc.

Similar durability of solar and furnace cured coating demonstrated in dish cycling tests!

BrightSource

2x2 m² automatic coating machine



Automatic coating machine

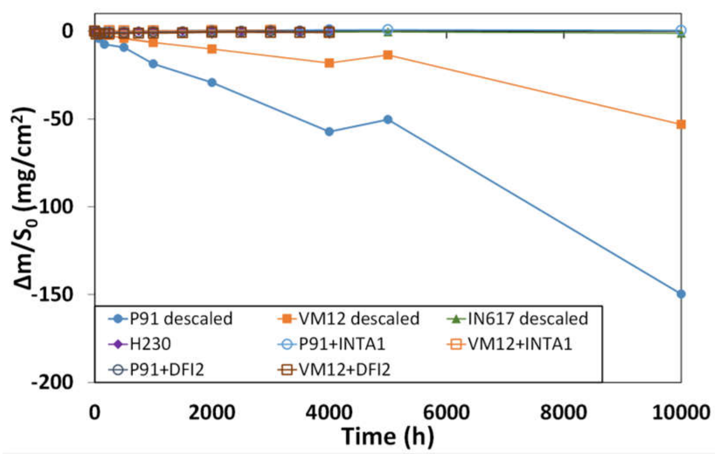
- Coating thickness tolerances: 5 µm (manual painting: 20 µm)
  → fewer coating “weak points”
  → higher durability expected

Corrosion protection coatings for molten salt

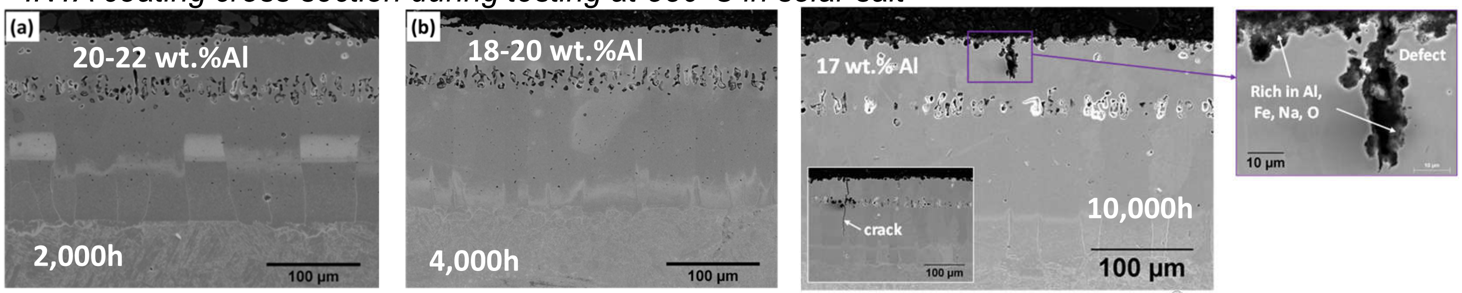
- Protective coatings: excellent performance after 10,000h of static testing in solar salt at 580°C
- Measured corrosion rates in solar salt at 580°C:
  T91: 169 µm/year
  VM12-SHC: 59 µm/year
  Inconel617: 15 µm/year (based on 4000h data)
- DECHEMA coating: corrosion layers up to 26µm have been measured under dynamic conditions (flow rate of 0.2m/s at 580°C)
- Minimum changes in coating thickness and surface Al-concentration for INTA coating also under dynamic conditions
- Weld joints of coated samples and showed very stable behaviour (tested up 1000h)

→ Coated FM steels have potential to reduce CSP cost, next step: demonstration under in-service conditions

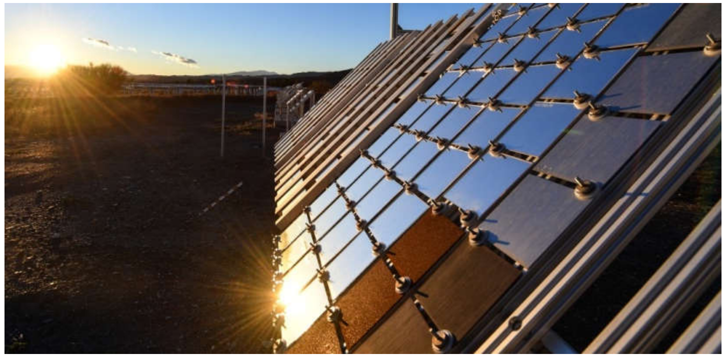
Static testing in solar salt at 580°C



INTA coating cross section during testing at 580°C in solar salt



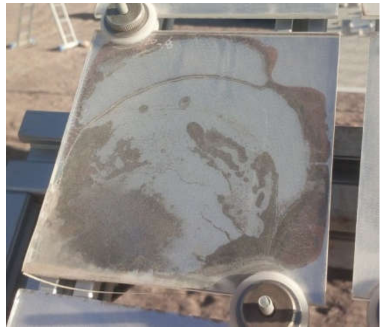
Coatings for solar reflectors



Mirror coatings tested in RAISELIFE:

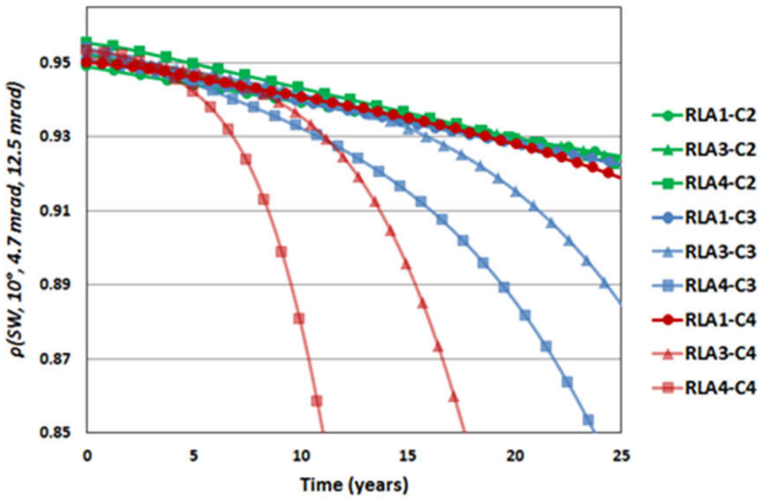
- 2 types of 2-layer systems (RLF2, RLF4) FLABEG
- Lead free (RLF3) FLABEG
- Powder lacquer (RLF5) FLABEG → failure
- Cost effective top coat AGC
- Reference 3-layer system (RLF1) FLABEG
- 6 types of anti-soiling coatings AGC, FLABEG, The Hebrew University of Jerusalem

Erosion of glass surface in Zagora



Corrosion of powder coated mirror in Antofagasta

- Low-cost 2-layer mirror coatings (RLA3, RLA4) suitable for sites of corrosivity C2. Stronger degradation than commercial reference in C3 and C4



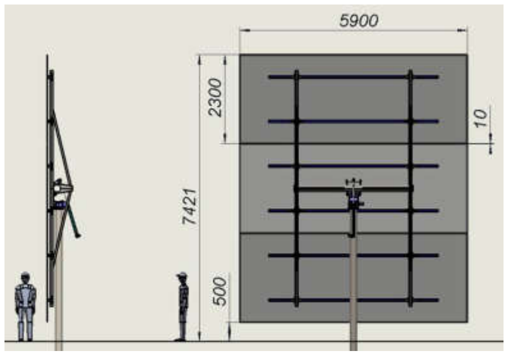
- Cleanliness gain up to 1.5%-p possible by use of anti-soiling coatings

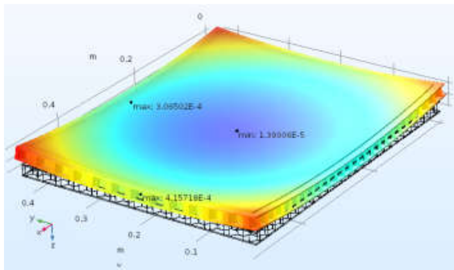
- Accelerated lifetime testing will be standardized in IEC

Thin glass composite heliostat

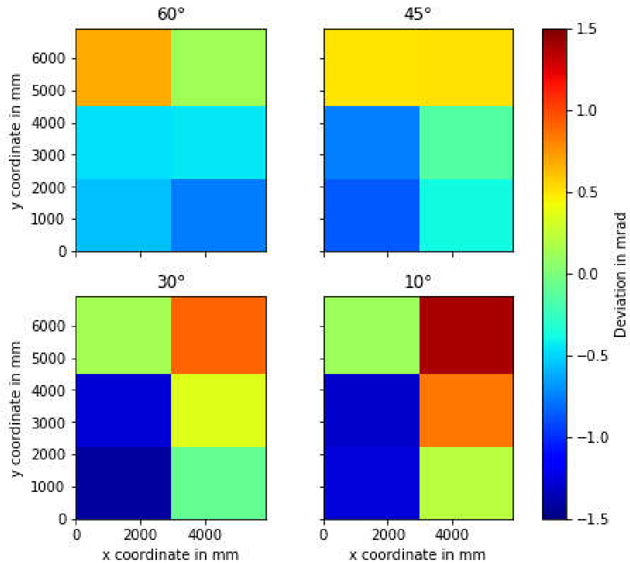
- 1mm thin glass was used instead of standard 4mm glass → increase of ~0.5% solar reflectance
- Composite material is used to improve resistance against breakage due to wind loads → prototype withstands winds up to 45m/s
- Lab and field laser scanning analysis showed deformation:
  - due to environmental temperature changes
  - due to the gravitational force acting on the large panel
  → optical efficiency losses of about 1%
- 40m² instead of current BSII design of 25.6 m² → potential cost reduction of 30%

Thin-glass composite heliostat at BSII, Israel, erected autumn 2018





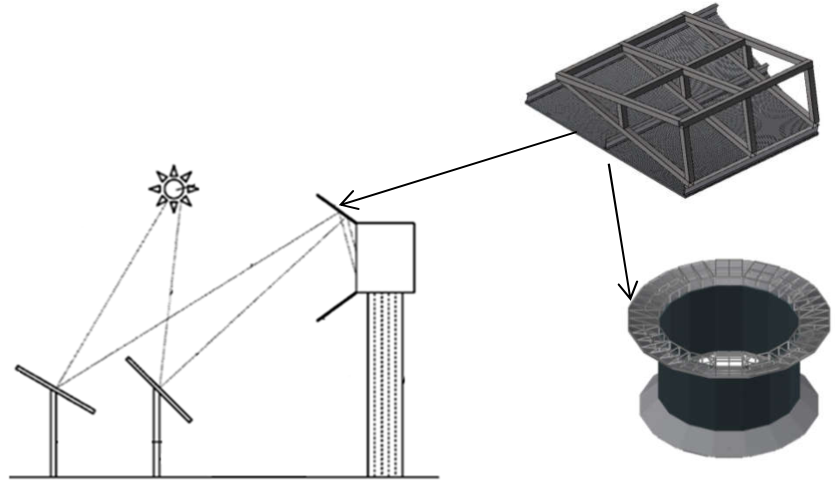
Deformation due to temperature changes measured in the lab



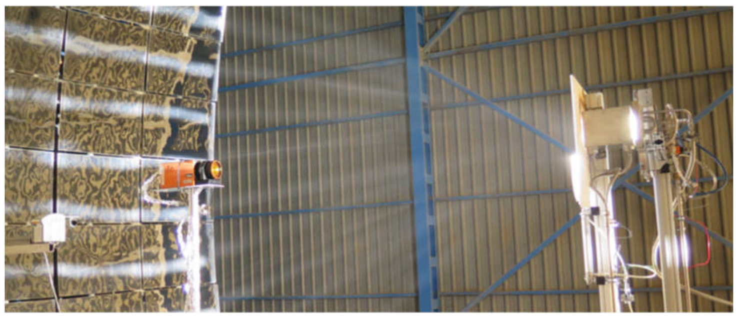
Measured slope deviation of the composite heliostat installed in Israel

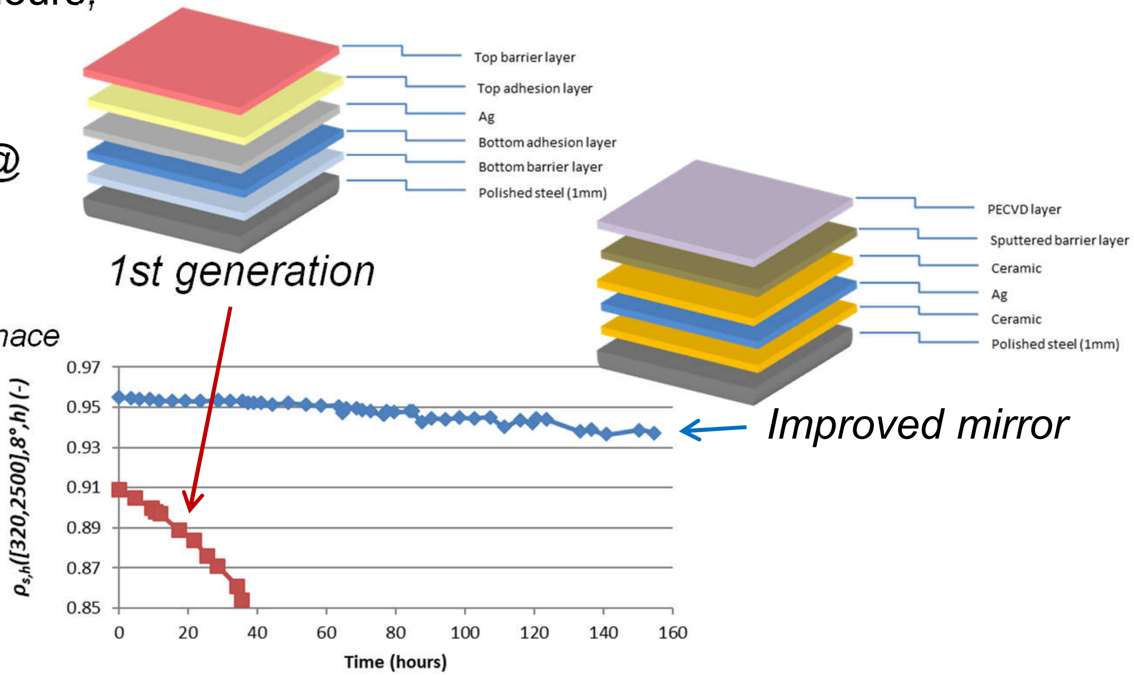
Secondary reflectors

- CAPEX savings of \$1.50M to \$1.83M are possible with secondary mirrors, mainly due to the reduction of panel height. (→LCOE reduction of ~1.9%)
- Fraunhofer secondary mirror reached ρ=95.5%
- 46 days tested under real operation conditions (380ºC, 350kW/m², 155 hours, 388 cycles) with a degradation to ρ=93.7%
- ρ stays above 92% for > 2 months @ 450ºC in muffle furnace test



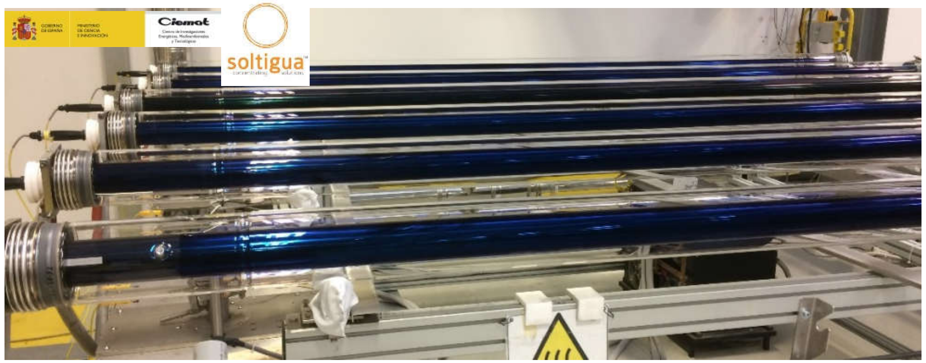
Testing of secondary mirrors in CIEMAT's solar furnace





Coatings for line focusing receivers

Anti-reflective coating for evacuated receivers



Coated receiver tubes at the ARCHIMEDE SOLAR factory

- High transmittance of τ =97.2%
- Increased abrasion resistance by factor 2.5 verified in Taber Abrasor test
- Stable after 1000h of Damp Heat test and 2000h of Condensation test
- Transmittance stayed between τ =95.1% - 96.1% after 12 months of field testing at Soltigua at 180°C, including 2 cleaning cycles per month.

Non-evacuated receiver coating

Testing of CIEMAT coating at SOLTIGUA at 180°C

- Produced by sol-gel dip coating
- α=95.5%, ε=13% (250°C), substrate: stainless steel
- α=95.5%, ε=9.1% (250°C), substrate: chromium coated stainless steel
- Coatings stable for >15 months in furnace at 400°C without degradation
- Negligible degradation after 14 months of field testing at 180°C by Soltigua
- Chromium coated stainless steel substrate starts to degrade at 450°C

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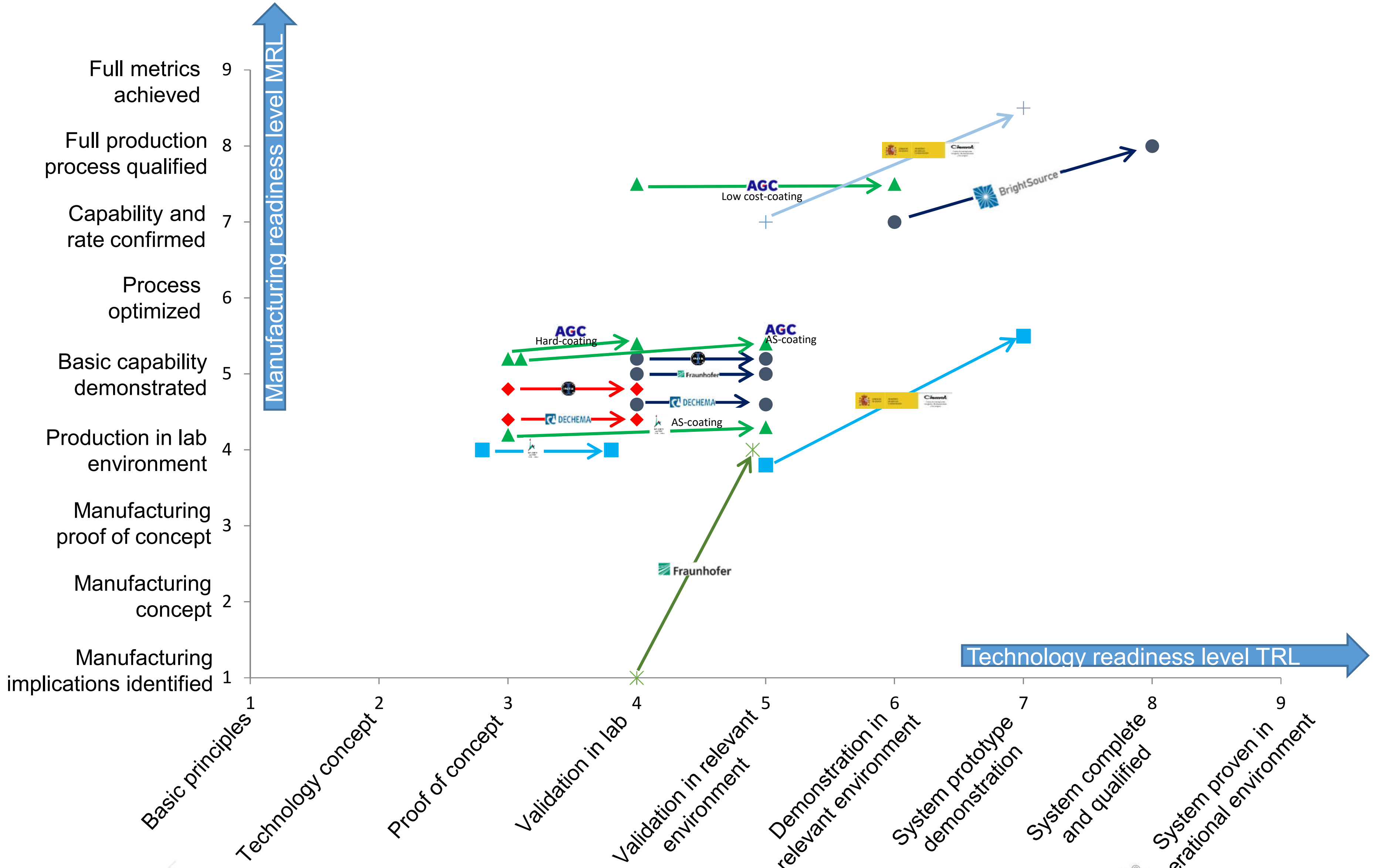
Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center
Fraunhofer
DECHEMA
BrightSource
vallourec
MAScIR
cnrs
AGC
UNIVERSIDAD COMPLUTENSE MADRID
INTA
soltigua
THE HEBREW UNIVERSITY OF JERUSALEM

TRL and MRL of RAISELIFE developments



RAISELIFE

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Exploitation and dissemination of RAISELIFE developments

- 14 published conference papers + 10 papers to be published still
- 13 peer reviewed publications
- 1 doctoral thesis
- 1 patent (protective absorber coating from Dechema)
- Exploitation brochure was uploaded on RAISELIFE website and EERA IP repository

Products ready for market

No.	Product	Improvement compared to state of the art	Contact person
1	Absorber coating for tubular solar tower receiver	α_s = 97%, ε = 85% (750°C) T_{max}= 750°C Lower degradation rate than Pyromark2500.	Mr. Yaniv Binyamin ybinyamin@brightsourceenergy.com Dr. Alina Agüero Bruna agueroba@inta.es
2	Absorber coating for tubular solar tower receiver	α_s = 95%, ε = 82% (750°C) T_{max}= 750°C Lower degradation rate than Pyromark2500.	Dr. Mathias Galetz galetz@dechema.de
3	Low-cost selective sol-gel absorber coating for non-evacuated parabolic trough receiver	α_s =95.4%, ε=7.8% (250°C) T_{max}= 400°C (stable for >15 months in furnace at 400°C without degradation).	Dr. Angel Morales Sabio angel.morales@ciemat.es
4	Anti-reflective coating for glass-envelope tube for evacuated parabolic trough receiver	τ_s =97.2% Improved abrasion resistance by factor of 2.5 compared to the state of the art.	Dr. Angel Morales Sabio angel.morales@ciemat.es
5	Low-cost protective coating for solar mirrors	2-layer instead of 3-layer coating systems for cost savings in dry desert sites of low corrosivity.	Mrs. Anne Attout Anne.Attout@eu.agc.com
6	Coating to prevent steel corrosion in molten salt	Negligible mass loss of coated sample after 10,000 h of furnace testing in solar salt at 580°C.	Dr. Alina Agüero Bruna agueroba@inta.es Dr. Mathias Galetz galetz@dechema.de
7	VM12-SHC steel qualified for CSP application	VM12-SHC may be employed in the low-temperature part of molten salt receivers instead of T91. Corrosion layer of VM12-SHC is 68µm compared to 193µm of T91 after 10,000 h of testing in solar salt at 580°C.	Dr. Javier Piron javier.piron@vallourec.com

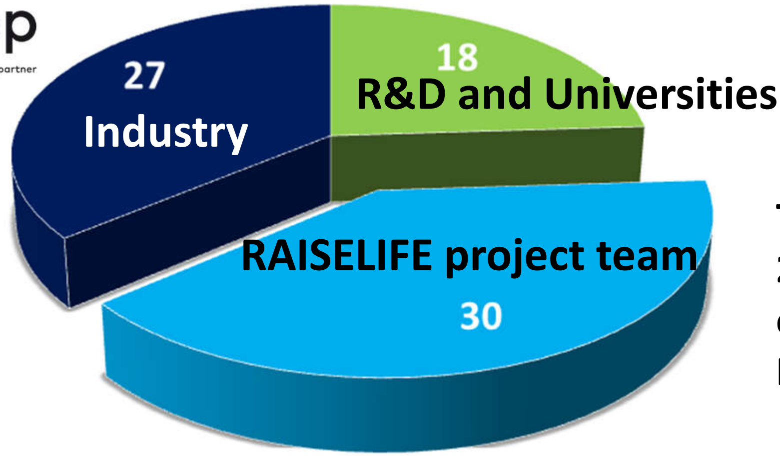
Services ready for market

No.	Service	Improvement compared to state of the art	Contact person
1	FREDA measurement system	Assess heliostat degradation of entire solar field.	Mrs. Anna Heimsath anna.heimsath@ise.fraunhofer.de
2	TraCS measurement device	Automatic collection of continuous soiling data on reflectors.	Dr. Fabian Wolfertstetter fabian.wolfertstetter@dlr.de
3	Sensor to monitor corrosion rates of steels in molten salt	Automatic collection of continuous corrosion data of structural materials.	Prof. Francisco Javier Pérez Trujillo fjperez@quim.ucm.es
4	Automatic coating machine of HSA absorber coating	Minimizes production cost, increases coating lifetime by homogeneous deposition, avoiding hot-spots (coating thickness tolerances of 5µm were achieved compared to 20µm with manual painting).	Mr. Yaniv Binyamin: ybinyamin@brightsourceenergy.com
5	Testing methodology for absorber coatings for solar tower receivers	Testing under concentrated solar flux and in climate chambers.	Dr. Florian Sutter florian.sutter@dlr.de Dr. Bernard Claudet claudet@univ-perp.fr
6	Testing methodology for secondary mirrors for solar tower	Testing under concentrated solar flux and in climate chambers.	Dr. Aránzazu Fernández-García arantxa.fernandez@psa.es
7	Testing methodology for primary mirrors	Outdoor exposure and climate chamber testing. Lifetime prediction based on accelerated aging testing.	Dr. Florian Sutter florian.sutter@dlr.de Dr. Aránzazu Fernández-García arantxa.fernandez@psa.es Dr. Sanae Naamane s.naamane@mascir.com
8	Testing methodology for anti-soiling coated mirrors	Outdoor testing in Spain and Morocco with regular cleaning intervals. Climate chamber testing.	Dr. Florian Sutter florian.sutter@dlr.de Dr. Aránzazu Fernández-García arantxa.fernandez@psa.es Dr. Sanae Naamane s.naamane@mascir.com
9	Testing methodology for corrosion in molten salt	Furnace and slow strain rate (SSRT) testing in molten salt at different temperatures.	Prof. Francisco Javier Pérez Trujillo fjperez@quim.ucm.es Dr. Alina Agüero Bruna: agueroba@inta.es Dr. Mathias Galetz: galetz@dechema.de Dr. Johannes Preußner johannes.preussner@iwm.fraunhofer.de
10	System simulation tools	Allow for economic assessment of novel materials, receiver and solar field efficiency computation.	Theda Zoschke theda.zoschke@ise.fraunhofer.de Ralf Uhlig Ralf.Uhlig@dlr.de

Preliminary developments with further optimization or testing needs

No.	Product	Improvement compared to state of the art	Contact person
1	Selective absorber coating for tubular solar tower receiver	α_s = 95%, ε = 28% (750°C) T_{max}= 750°C Optimization of durability is ongoing	Dr. Christina Hildebrandt christina.hildebrandt@ise.fraunhofer.de
2	Low-cost absorber coating for non-evacuated parabolic trough receiver	α_s=96.6%, ε=80.0% (20°C) Carbon nanotube based spray-coating. Optimization of durability is ongoing.	Prof. Daniel Mandler daniel.mandler@mail.huji.ac.il
3	Anti-soiling coating for solar mirror	Increased cleanliness of solar field up to 1.3% after 6 months of testing.	Mrs. Anne Attout Anne.Attout@eu.agc.com Prof. Daniel Mandler daniel.mandler@mail.huji.ac.il
4	Ultra-thin glass mirror of high reflectance	200µm flexible glass mirror with solar reflectance of ρ=96% (1.5%-p higher than state of the art reflectance).	Dr. Michel Prassas PrassasM@corning.com
5	High-reflectance composite heliostat	Low-weight due to composite material; high reflectance due to first surface mirror; able to withstand high wind-loads	Mr. Yaniv Binyamin: ybinyamin@brightsourceenergy.com Mr. Yoel Gilon: ygilon@brightsourceenergy.com

2nd RAISELIFE Dissemination Workshop



Total: 75 participants
23 presentations are available on the public section of the RAISELIFE website

Thank you for your attention!