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High-performance Stellio heliostat for high temperature application

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STELLIO

next-CSP

Contents

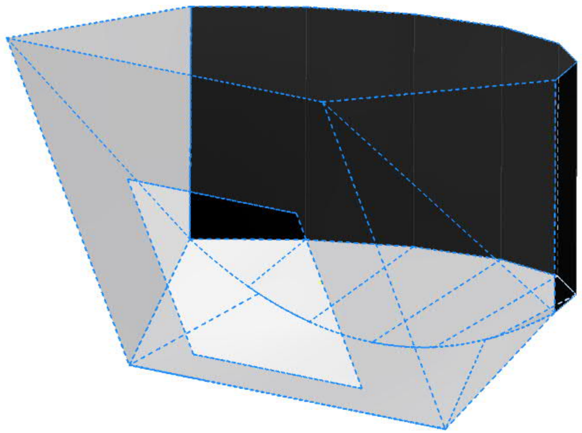
1. Introduction

Motivation for high performance heliostats

High temperature processes mean:

→ High surface temperatures of receivers/absorbers

→ Increased thermal losses (IR radiation goes with T^4)



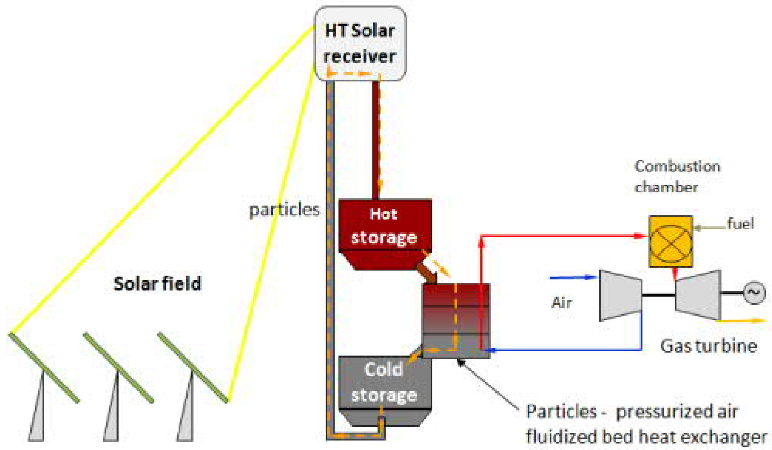
System design requirements:

- Cavity receivers!
- Apertures: as small as possible
- Heliostats: high optical quality (small beam diameter), low tracking errors

next-CSP (1)

EU funded project:

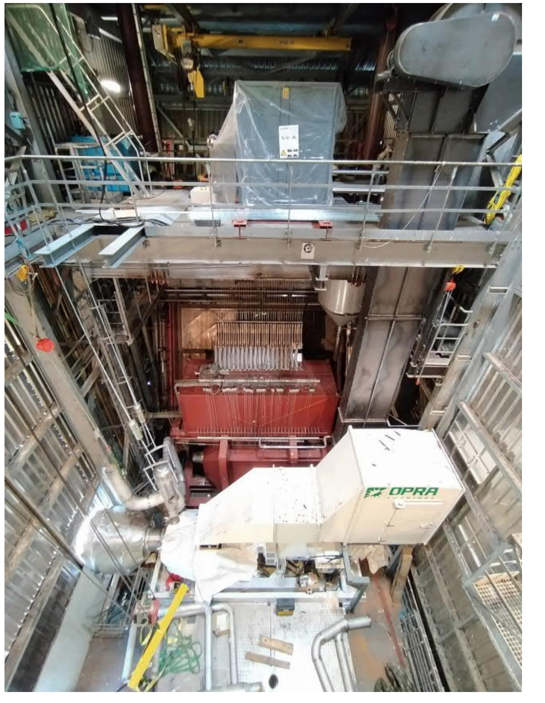
- Fluidized particle-in-tube receiver for 750 °C
- Particles used as thermal storage
- 3 MW_{th} prototype receiver (Whittaker Engineering) at Themis plant in Odeillo/France, to be completed in 2020, operated by CNRS



next-CSP (2)

Further presentations and posters on next-CSP:

- A. Le Gal et al., "MW-scale prototype of the fluidized particle-in-tube solar receiver. Design, control and first experiments at Themis tower.", presentation given in **WED-1A, 11:10**
- B. Grange et al., "Simulation of the Next-CSP solar loop including a hybrid gas turbine", presentation given in **WED-2D, 15:50**
- B. Grange et al., "Comparison of simulated and measured flux distributions at the aperture of the Next-CSP solar receiver", presentation given in **WED-1C, 11:10**
- F. Siros et al., "Next-CSP Concept with Particle Receiver Applied to a 150 MWe Solar Tower", presentation given in **FRI-1C, 10:50**
- Sahuquet, G., "Particle Flow Stability in Tubular Fluidized Bed Solar Receivers", 26th SolarPACES conference, 2020 – **poster session Receivers Tues 18:15**
- K. Whittaker, Keith Watt, "Manufacturing of the Main Components of the Next-CSP Project Solar Pilot Plant", **poster session Advanced Materials Mon 16:00**



Partially installed receiver at Themis

Stellio heliostat

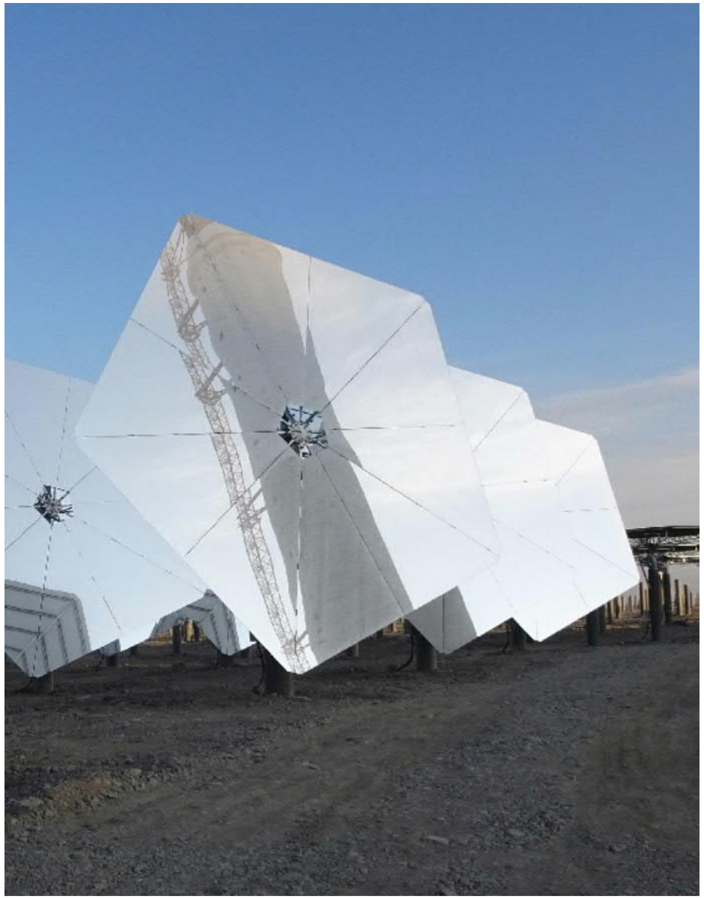
Stellio: developed for large plants, commercially available

Selected for Hami Solar Tower/China (under construction)

Main characteristics:

- Net reflective surface: 48.5 m²
- Novel kinematics with inclined axes (slope drive)
- Two linear actuators
- Reflector substructure with high stiffness
- High optical quality

www.stellio.solar



2. Heliostat quality parameters

- Slope error:

$$\sigma_{beam} = 2 \times \sigma_{slope}$$

$$\sigma_{slope,2D} = \sqrt{\sigma_{slope,x}^2 + \sigma_{slope,y}^2}$$

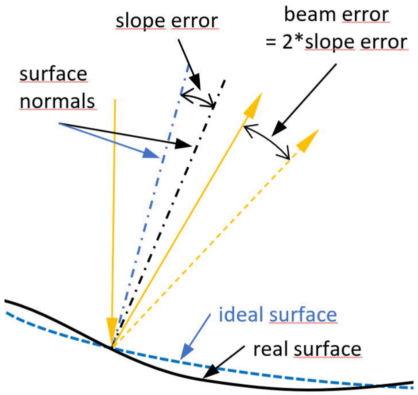
→ Stellio: $\sigma_{slope,2D}$ (SD_{tot}) = 1.5 mrad

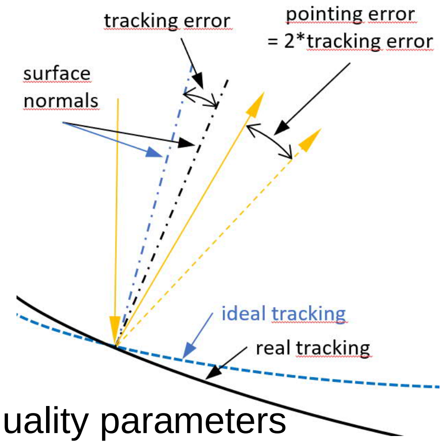
- Tracking error:

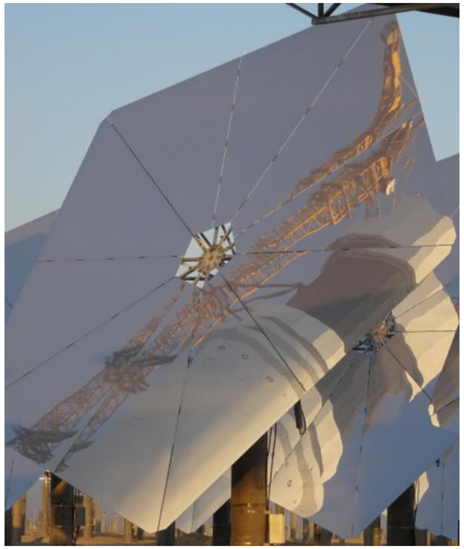
$$\sigma_{pointing} = 2 \times \sigma_{tracking}$$

$$\sigma_{tracking,2D} = \sqrt{\sigma_{tracking,x}^2 + \sigma_{tracking,y}^2}$$

→ Stellio: $\sigma_{tracking,1D}$ = 0.6 mrad







3. Optical quality improvements

Potential improvements

Measures	Potential	Engineering effort	Cost increase
Increase of purlin stiffness	++	medium	low
Increase of cantilever arm stiffness	+	medium	low
Increase number of mirror supporting points	+++	high	medium
Modification of supporting point details	+	medium	medium
Increase facet stiffness	+++	high	high

Identify improvement measures for optical quality

Potential improvements

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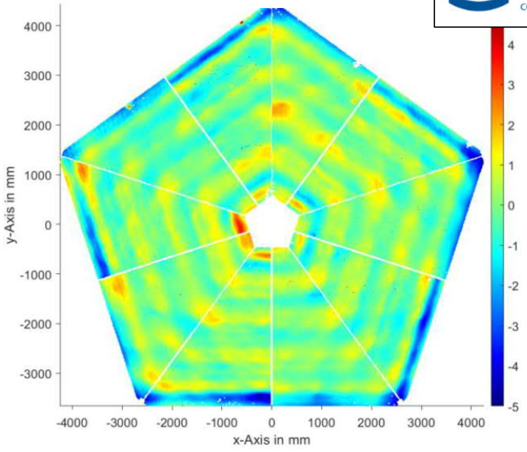
Standard Stellio slope errors

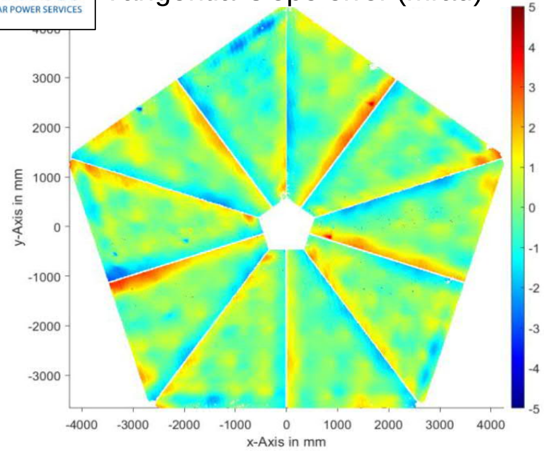
Example of slope errors from Hami field: heliostat #6813, Aug. 2020

SD_{tot} = 1.27 mrad

Radial slope error (mrad)

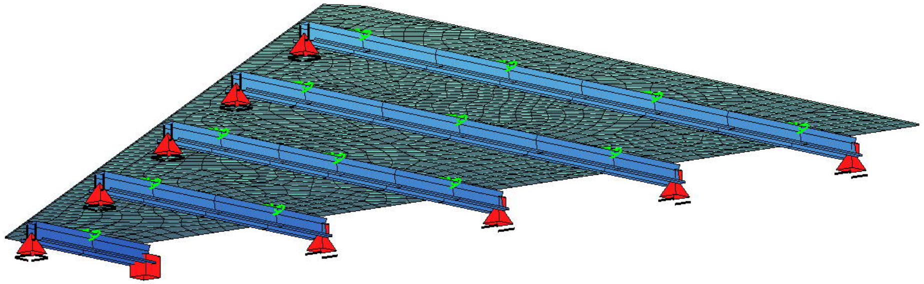


Tangential slope error (mrad)



Standard Stellio mirror supporting

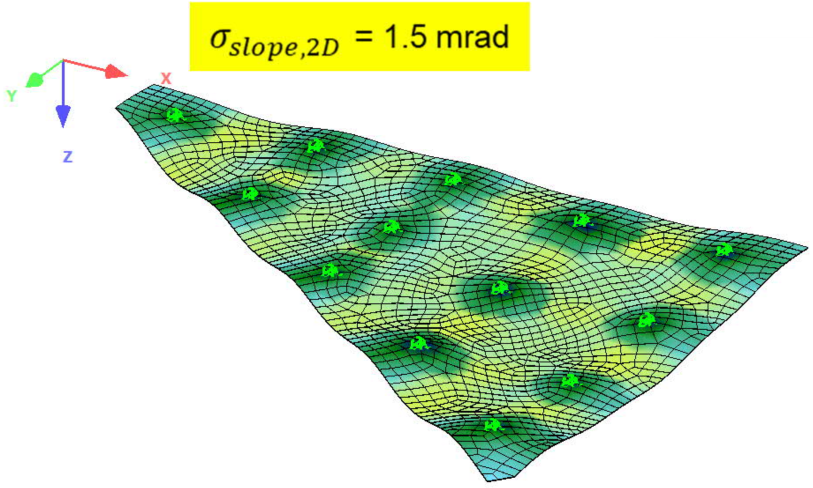
Stellio mirror support structure



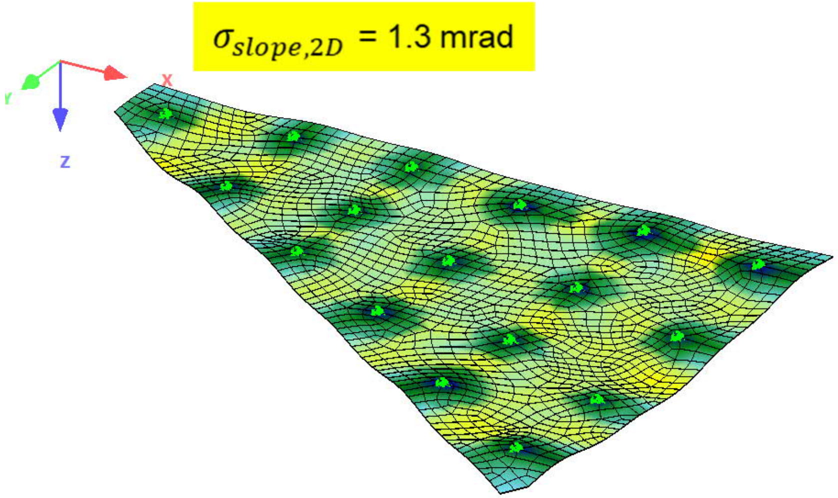
Facet with 5 purlins and 13 supports

Optical quality improvements

Mirror deformations under deadweight



Facet with 5 purlins and 13 supports



Facet with 6 purlins and 17 supports

Cost impact

Extra cost for additional purlins
and mirror supports, incl. assembly:

Approx. 2 % of heliostat cost (wo. foundations)

4. Tracking quality improvements

Potential improvements

Measures	Potential	Engineering effort	Cost increase
Reduction of actuator backlash	++	medium	medium
Reduce tolerances of spindle pitch	+	low	medium
Increase actuator stiffness (ball screw)	+	medium	high
Increase limit switch precision	+	low	low
Improve actuator corrections by control (temperature, normal force, pitch)	+	high	zero
Increase pylon head stiffness	+++	medium	low
Refinement of heliostat calibration	++	high	low

Identify improvement measures for tracking quality

Potential improvements

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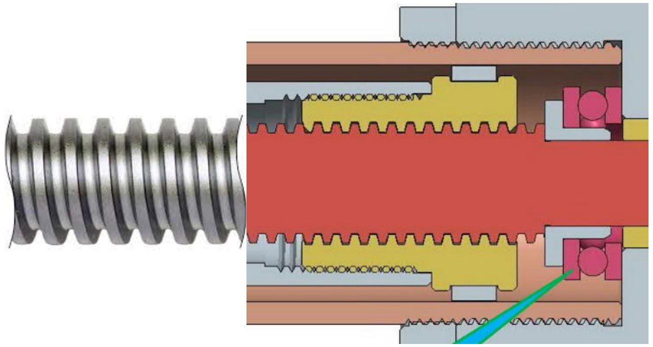
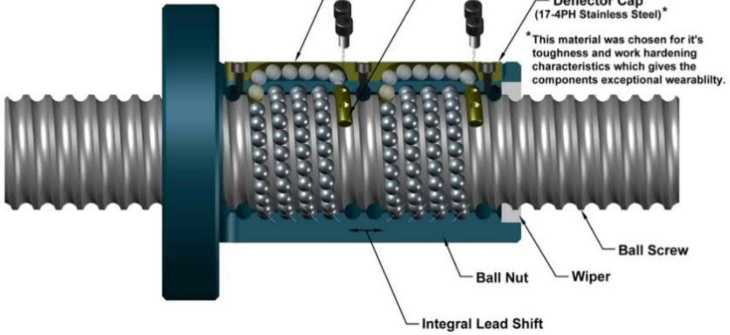
Linear actuators (1)





www.barnesballscrew.com

ACME spindle and nut

- Trapeze groove, plastic nut
- Sliding contact
- Low efficiency

Ball screw spindle and nut

- Circular groove, nut with steel balls
- Rolling contact
- High efficiency

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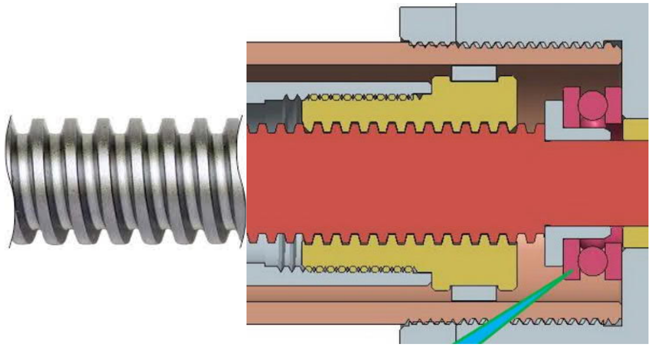
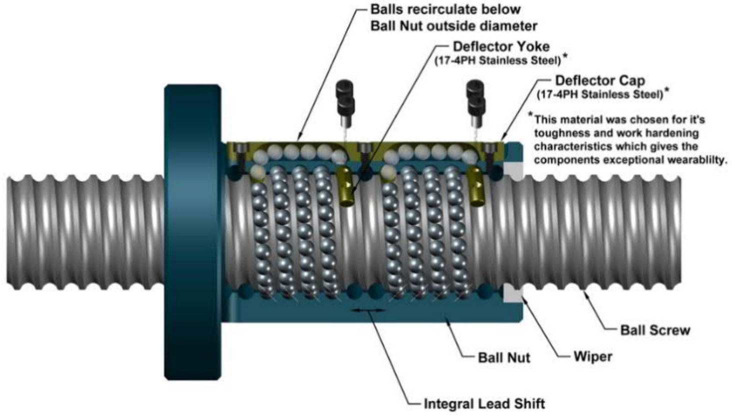
Tracking quality improvements

Linear actuators (2)





www.barnesballscrew.com

ACME spindle and nut

- Backlash temperature dependent, subject to wear
  → **1.0 mm avg.** over service life*
- Medium stiffness, considerable loss in plastic nut

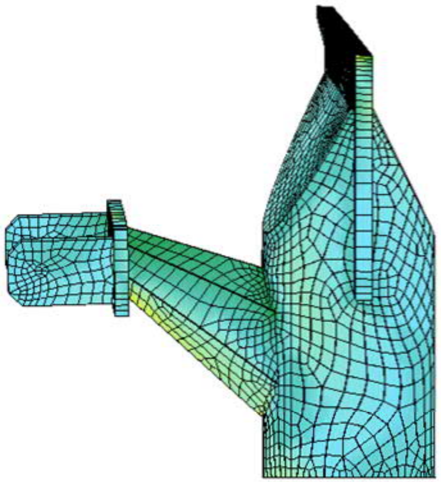
Ball screw spindle and nut

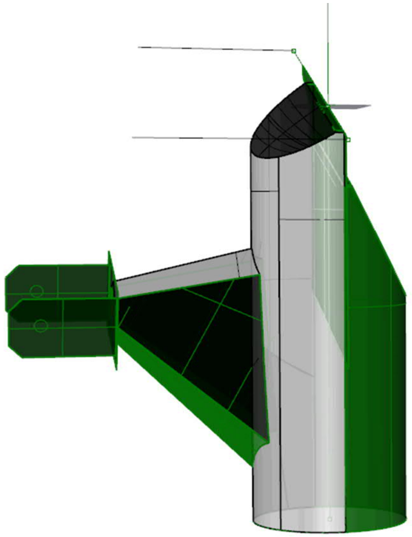
- Backlash almost constant, little wear
  → **0.3 mm avg.** over service life*
- High stiffness, all parts from metal
  → **2-3 fold** of ACME

* incl. trunnion and rod end bearing play

Increased stiffness of pylon head

- Modified geometry + optimized material thickness → increased stiffness
- Mass remains constant





Improved calibration

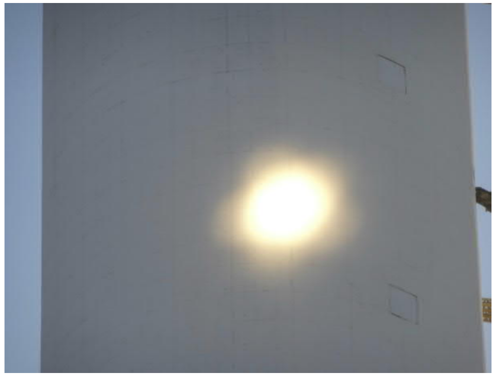
1. Beam Characterization System (BCS):
Target/camera based → novel calibration solutions, e.g. drone based

Advantages:
- independent of sun, clouds and target availability
- potentially better accuracy
- high calibration frequency.

→ System developed together with CSP Services and others in HelioPoint project (W. Jessen et al.: A Two-Stage Method for Measuring the Heliostat Offset, **Poster session Measurement Systems, Wed 18:45**

2. Algorithm for tracking error corrections:
Potential for improvement, can‘t yet be quantified

→ Estimated uncertainty of measured beam pointing reduced by half



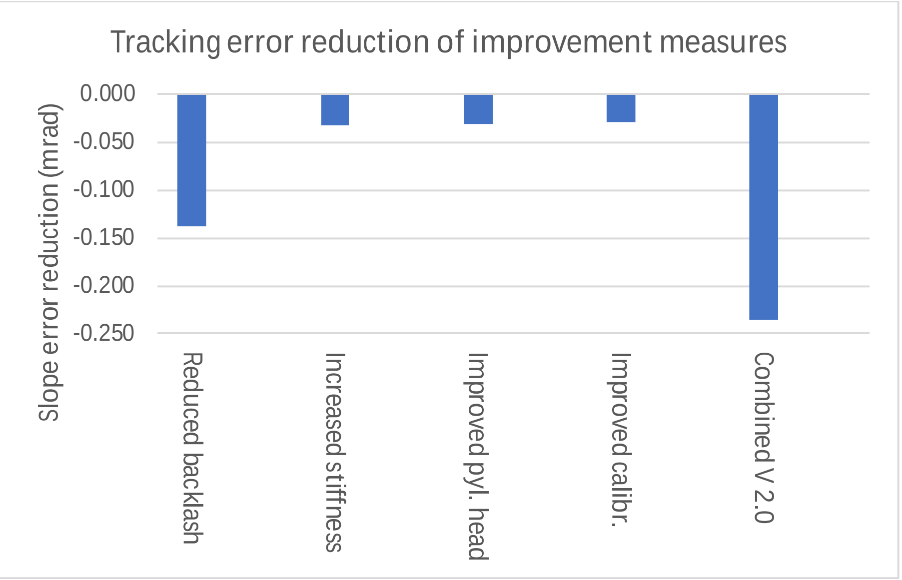
Combined tracking error

Total tracking error is combined from:
- backlash
- drive stiffness
- pylon/foundation/structure stiffness
- calibration/tracking algorithm accuracy

Dead weight induced errors are compensated to a good part but wind effects remain.

All errors are overlaid by RMS.

→ Reduction from 0.6 to 0.4 mrad is expected (1D)



Cost impact

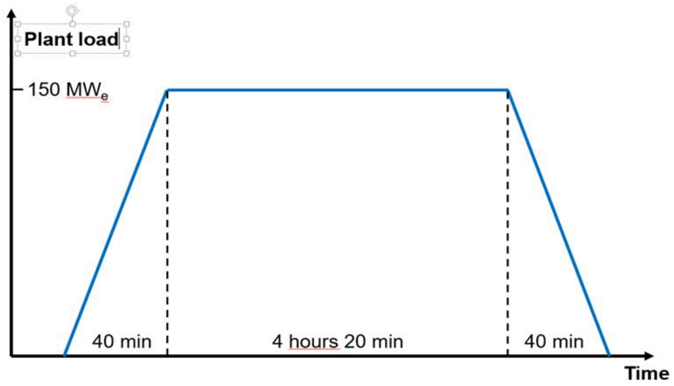
- Ball screw actuator cost: approx. 30-40 % higher than ACME
- Pylon head improvement cost: ±0
- Precise calibration cost: ±0

→ approx. 5 % increase of heliostat cost (wo. foundations)

5. Techno-economic analysis

LCoE analysis by EdF

- Simple model, O & M cost neglected since these are same for all options
- Discount rate: 4 %, lifespan: 25 years
- Sample power plant assumed, using next-CSP technology:
  - Peaker plant, 150 MW_{el}
  - CSP full load: 5 hrs
  - Daily thermal / electric energy: 1.6 GWh / 0.75 GWh
- Specific LCoE changes:
  +1 M€ in CAPEX results in LCoE change of +0.28 €/MWh_{el}
  +1 MW_{el} in net output results in LCoE change of -0.63 €/MWh_{el}



LCoE analysis results

Reference system		
Receiver outlet power	343	MW_{th}
Plant net electric power	150	MW_{el}
CAPEX	340	M€
LCoE	95	€/MWh_{el}

High performance Stellio				
Improvement measures		CAPEX increase (M€)	Performance gain (MW_{th})	LCoE change (€/MWh)
Slope error		1.55	4.93	-0.93
Tracking error		4.16	5.78	-0.44
Combined		5.71	10.71	**-1.37**
	Percental			-1.44%

~1 % (Slope error)

~0.5 % (Tracking error)

Tracking error improvement	
Improvement measures	LCoE change (€/MWh_{el})
Ball screw actuator	0.02
Improved pylon head	-0.34
Improved calibration	-0.33

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Techno-economic analysis

6. Conclusions

- Overall, LCoE reduction of approx. 1.5 %
- Major gain by increased number of mirror supports

Notes:
- Conceptual study, no/little optimization
- Simplified calculations were applied

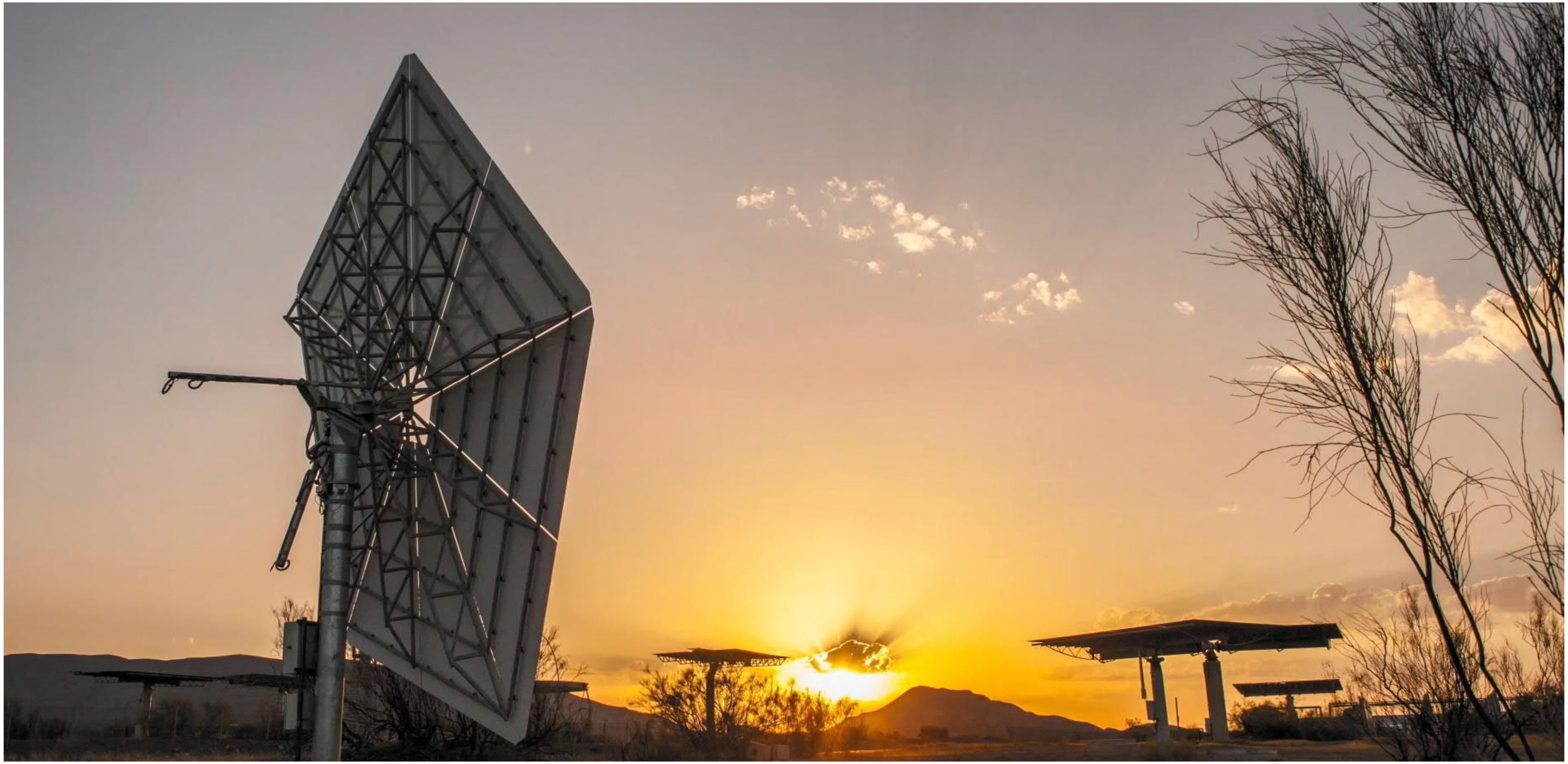
→ **High performance Stellio provides some economic advantage for high temperature processes**

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 727762, project acronym next-CSP.

European Commission

Horizon 2020
European Union funding
for Research & Innovation



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Thank you very much for your attention!