SFERA-III

Solar Facilities for the European Research Area

1st Summer School "Thermal energy storage systems, solar fields and new cycles for future CSP plants"
WP1 Capacity building and training activities
Odeillo, France, September 9th-11th 2019

Solar Facilities for the European Research Area

"New concepts of heliostats for solar tower systems""

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NETWORKING

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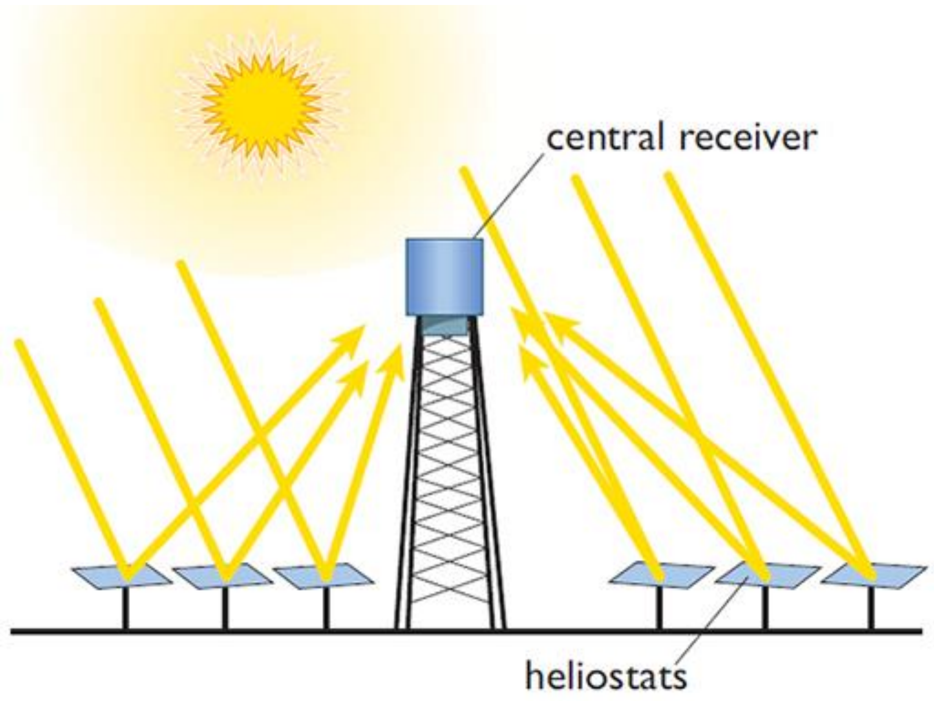
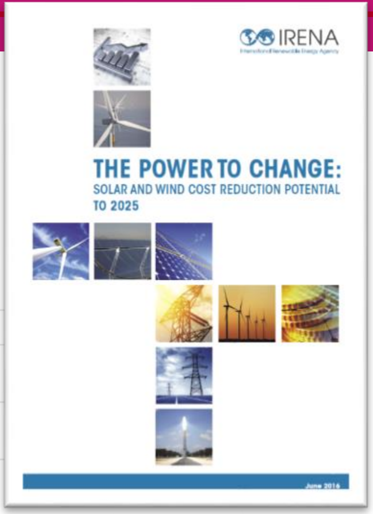
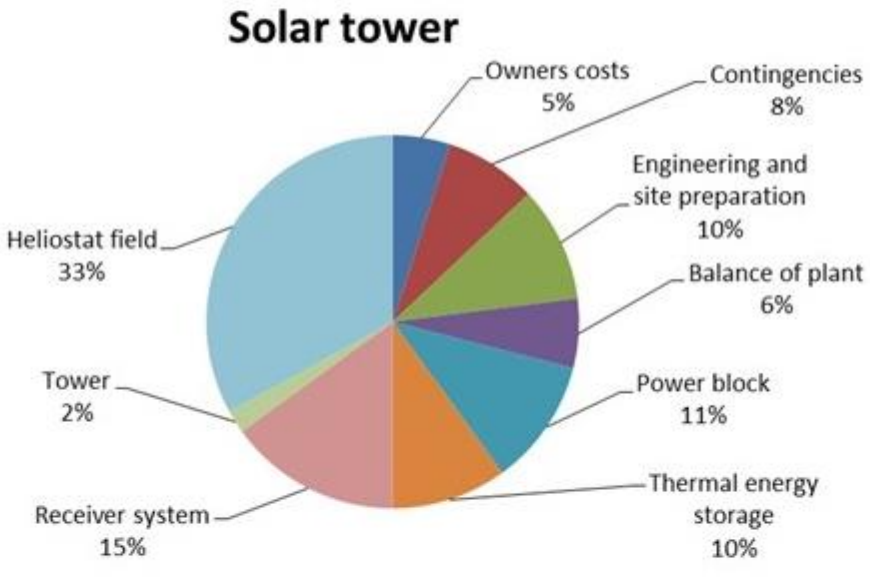
Outline

- Context
- Heliostats design
- Big vs. small heliostas
- Current concepts under development (attention, may be your heliostat is missing)
- Conclusions and perspectives

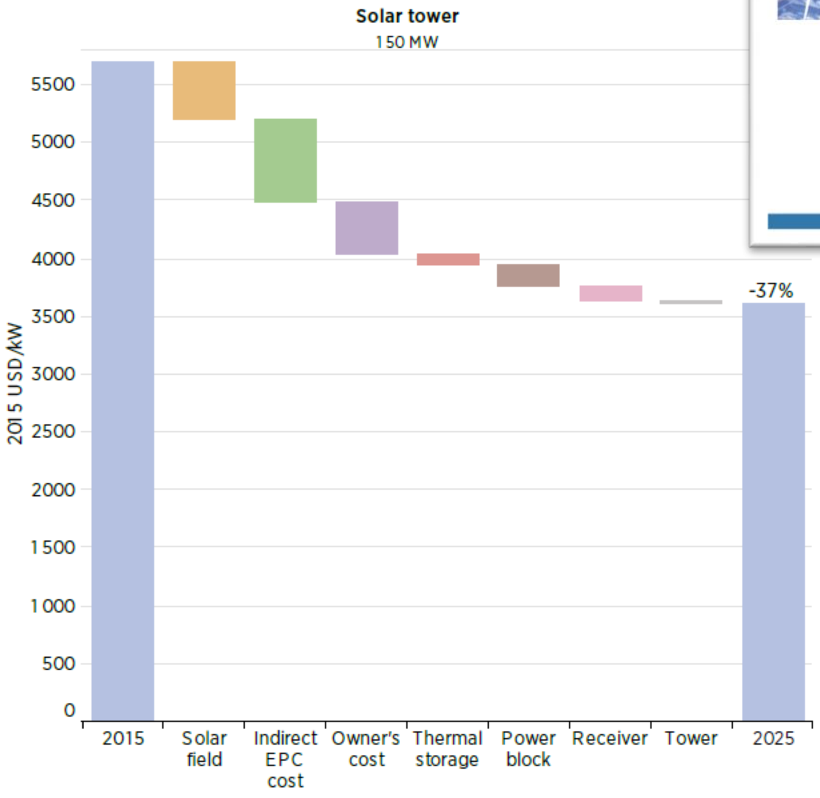

central receiver
heliostats



Impact of heliostats cost in solar thermal power plants

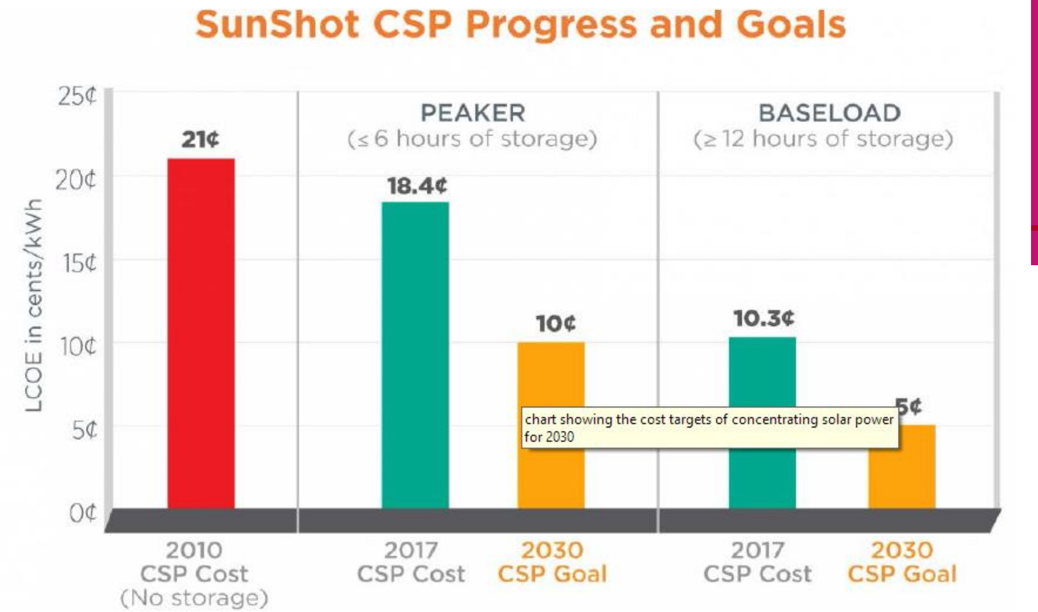


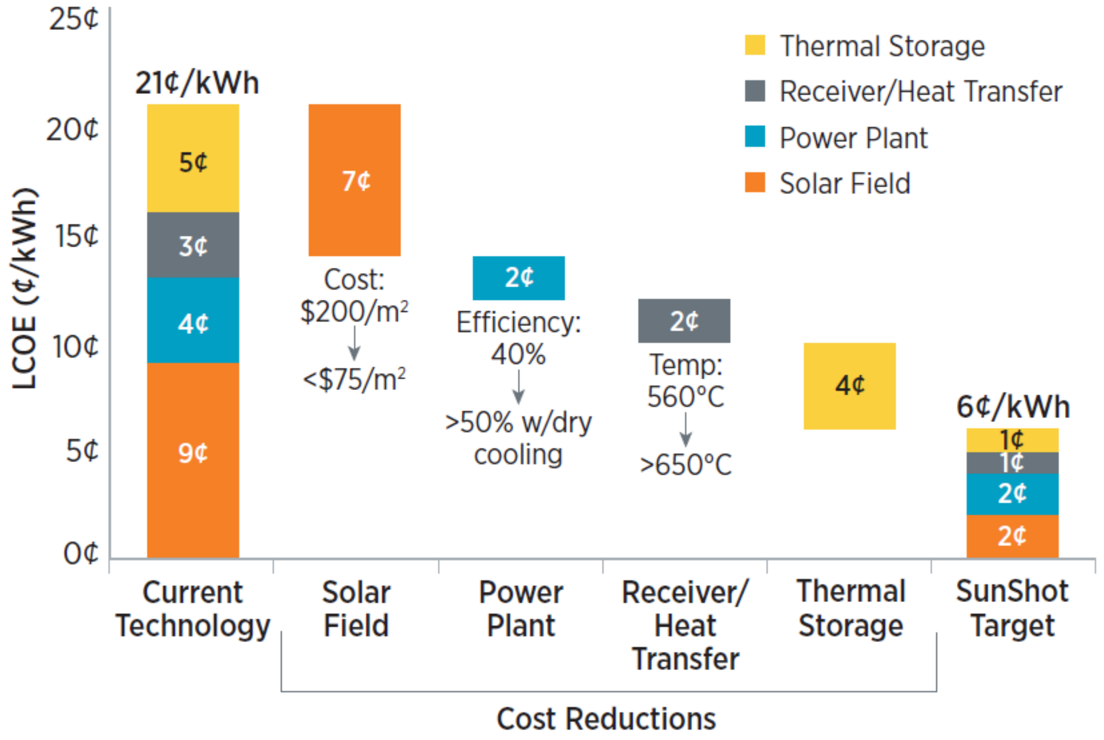
SOURCE: FICHTNER, 2012



Source: IRENA and DLR, 2016.

Impact of heliostats cost in solar thermal pow





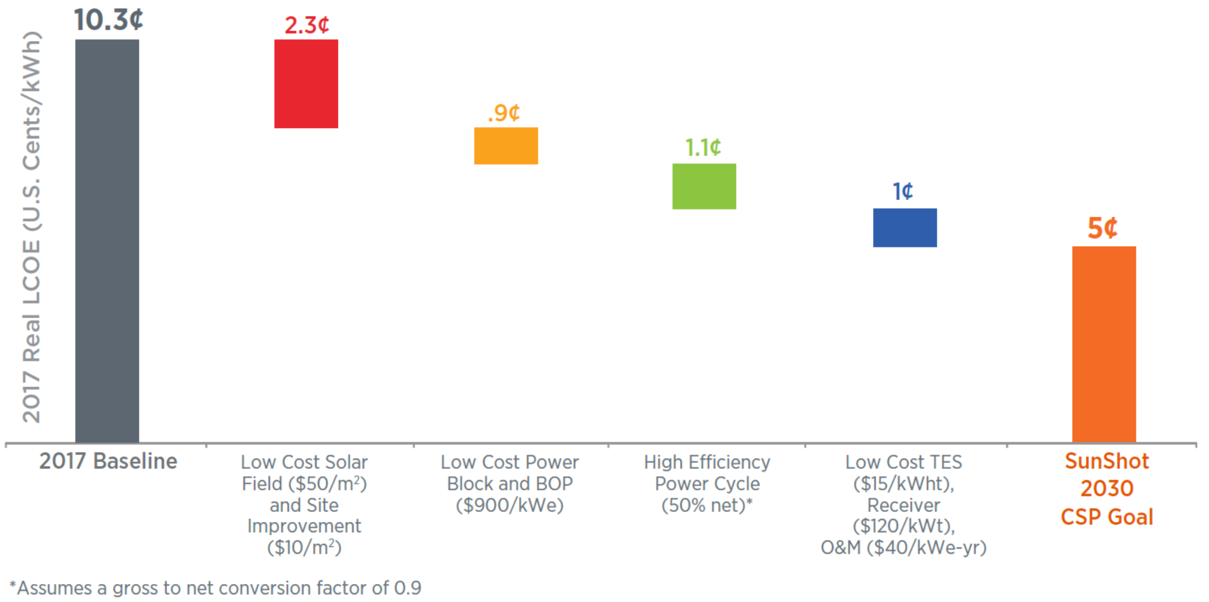
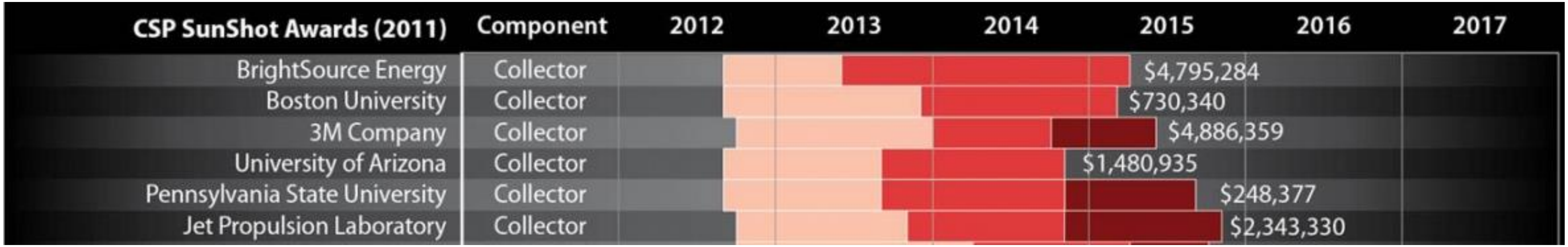


Figure 5. Example modeled pathway toward 5¢/kWh for baseload CSP.

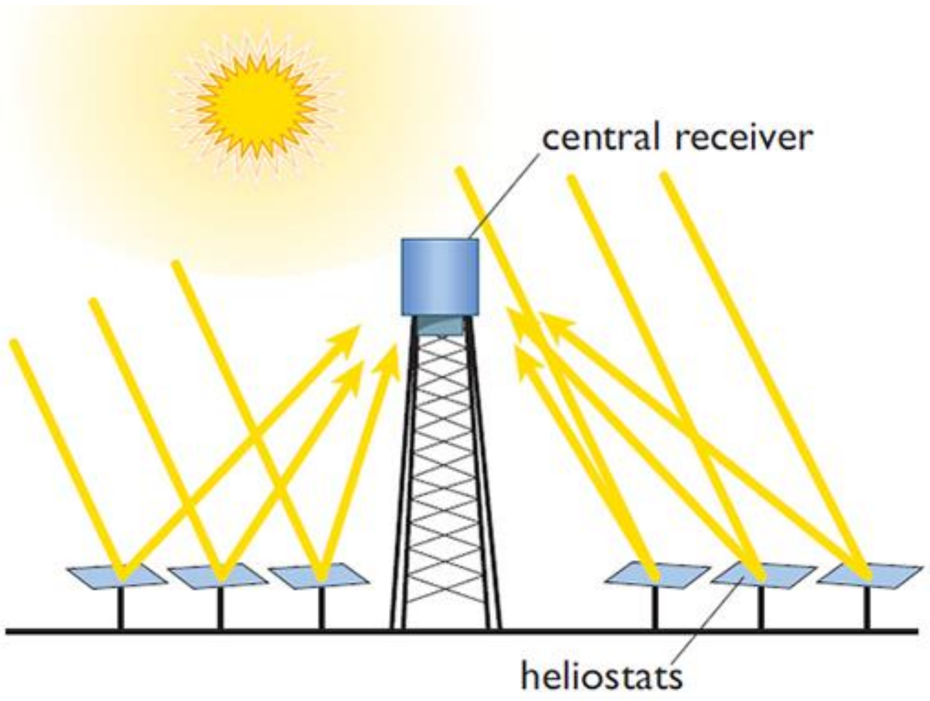


Funding Program	Year Announced	Amount Awarded
Concentrating Solar Power: Concentrating Optics for Lower Levelized Energy Costs (CSP: COLLECTS)	2016	$9M

SOLAR DYNAMICS LLC
Project Name: Drop in, Ring of Power Heliostat for Collects
Location: Broomfield, CO
SunShot Award Amount: $2,062,246; **Awardee Cost Share:** $850,436
Project Summary: Solar Dynamics is building on heliostat technology developed under a previous award in the Baseload CSP funding program to develop the DROP C (Drop-in, Ring-Of-Power Heliostat for COLLECTS). The new design allows the heliostats to be dropped into a location with drastic reduction of the preparation of the site location, which enables a reduction in costs and improves financing terms. The addition of a wide base and protected drives, which permit heliostats to move and reflect sun at the best angle, allows lower manufacturing costs, reduced costs for the structure's support, and increased protection from high winds. These improvements, coupled with wireless control of the heliostats, support lower cost targets well beyond the SunShot 2020 goals.

Target on reduction of heliostats cost

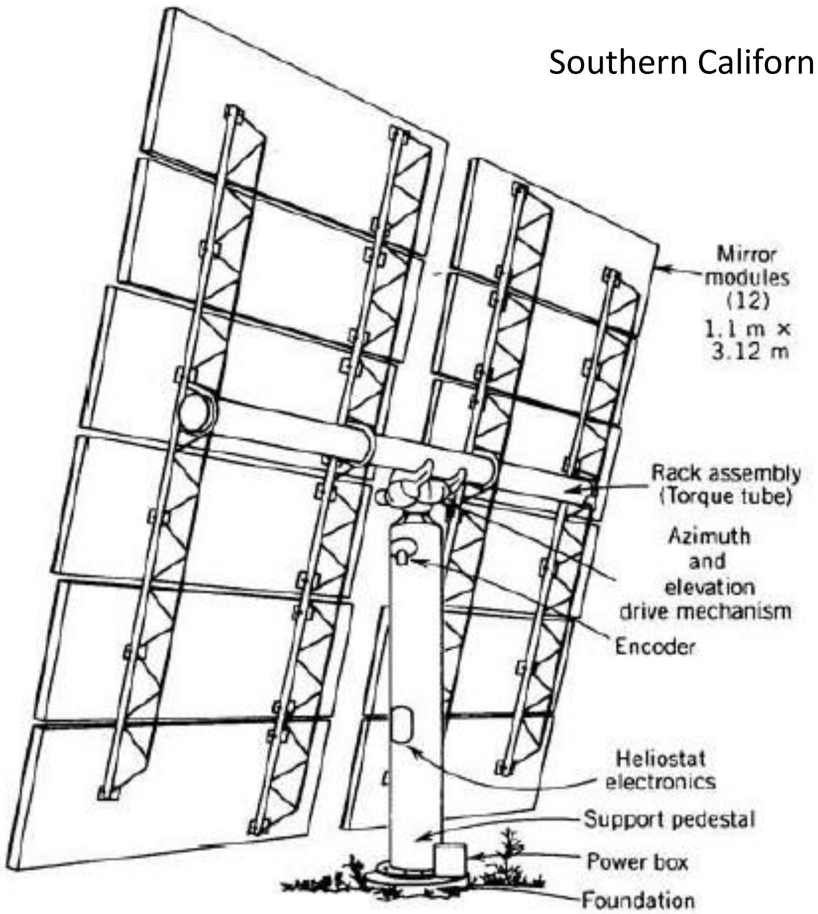
- USA, SunShot, 50 $/kWh, 75 $/m^2
- Australia, Australian Solar Thermal Research Initiative, ASTRI, 90 AUD/m^2
- South Africa
- EU, STAGE-STE KPI, 100 €/m^2


central receiver
heliostats

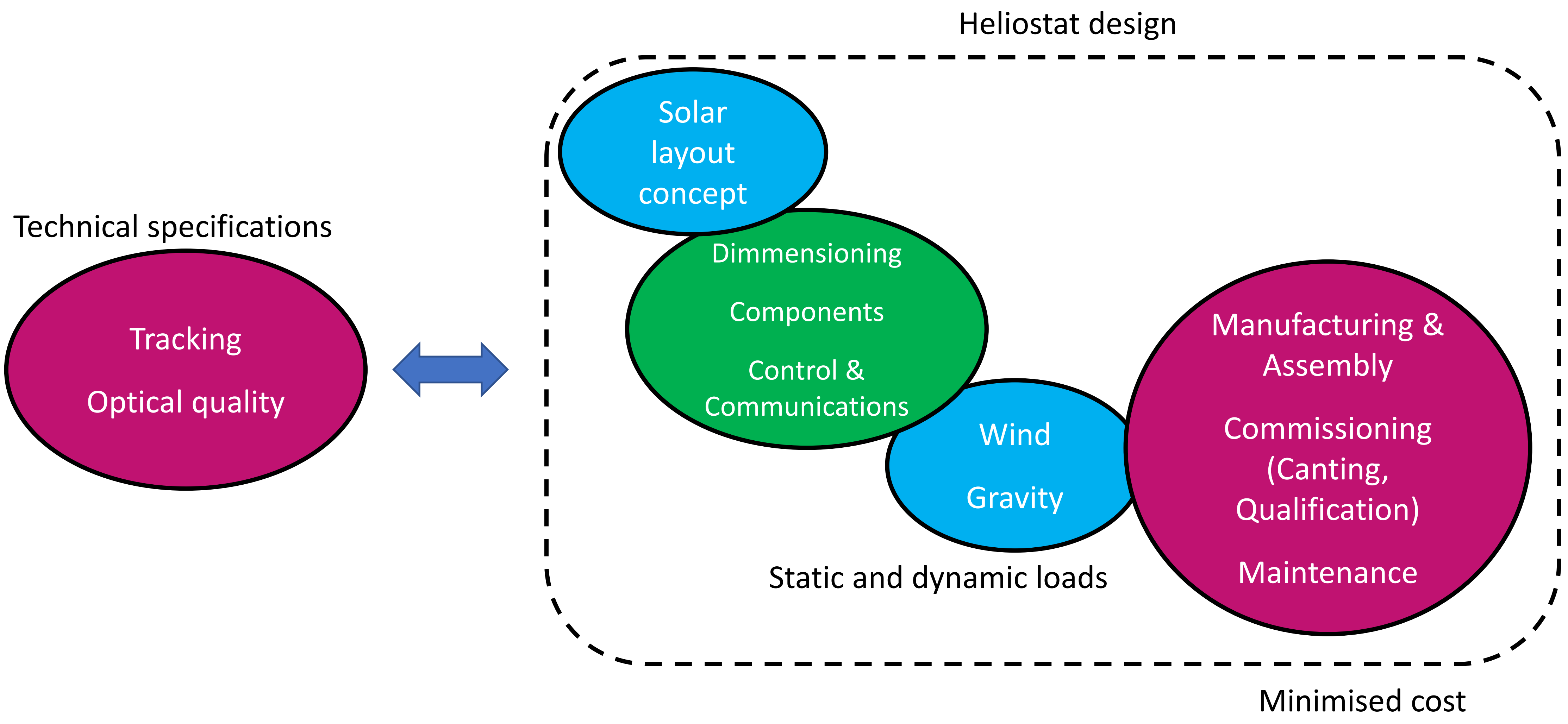
Heliostat components

Heliostat component	Sub-elements
Reflecting module	▪ Mirror modules / facets ▪ Frame / rack assembly
Foundation	▪ Foundation / Ground anchorage
Structure	▪ Support structure
Drive mechanism	▪ Azimuth and elevation drive ▪ Gear box ▪ Cabling
Control	▪ Position sensor ▪ Interface with power system and heliostat field controller ▪ Drive controller ▪ Wiring ▪ Master control interface electronics for heliostat local control ▪ Time base, computers, software
Support equipment	▪ Handling equipment ▪ Maintenance trucks and equipment ▪ Heliostat washing equipment ▪ Operating procedures (including offset error corrections, …) ▪ Maintenance Procedures

Southern California Edison



(a)


Heliostat design
Technical specifications
Tracking
Optical quality
Solar layout concept
Dimmensioning
Components
Control & Communications
Wind
Gravity
Static and dynamic loads
Manufacturing & Assembly
Commissioning (Canting, Qualification)
Maintenance
Minimised cost

Primary factors for heliostat definition

- The size (e.g. area of reflective surface) directly impacts other critical parameters for the design and for the cost such as the weight, wind load, time of construction and installation.
- The optical design covers the general design of the heliostat: nature of the reflective material (e.g. silvered glass, aluminum, polymer-based silver film, etc.), number of facets, shape (e.g. curvature), and orientation (e.g. elevation-azimuth vs. tilt-azimuth, target-aligned vs. zenith axis).Tracking

Secondary factors

- Mechanical structure and pedestal
  - General design (mast anchorage to the ground, beam, girder, box vs. truss…)
  - Material (steel, aluminum, concrete…)
  - Assembly (welding, bolts, rivets, glue…)
- Motors and drives
  - Main power supply (electric vs. hydraulic or pneumatic)
  - Type of motor (DC motors, synchronous motors, asynchronous motors, stepping motors)
  - Reduction step (direct drive, gear box, drive belt, chains, cable)
  - Actuator type (linear vs. rotating)
- Tracking controls, security systems
  - Open-loop vs. closed-loop
  - Local controller vs. central controller
  - Wireless communication vs. wired system
  - Heliostat concept connections (autonomous vs. grid connected)

Reflecting module

- Mirror: silvered glass, aluminum, polymer-based silver film…
- Mirror support structure (fixing mirror shape): Connection of glass mirrors to steel frames, Stamped mirror facet support structure, Sandwich panel mirror facets, stretched membrane,

Pylon and foundations (ground connection)

- Steel reinforced concrete piers, pile driving, ground anchor, and ballast type foundations

Structure (degrees of freedom)

- T-type (open, closed)
- Pitch/roll, rim drive, carousel

Drive mechanism

- Rotary electromagnetic motors, Hydraulic actuators
- Worm gears, spur gears, screw and nut, chain and pinion, harmonic drive configuration gears ("strain wave gears"), planocentric drives, rack and Pinion, linear drives, friction wheels, capstan drives.

Control

- Local to each heliostat (field wiring to a central system); autonomous heliostats (PV panels, wireless communication)


Spur gear

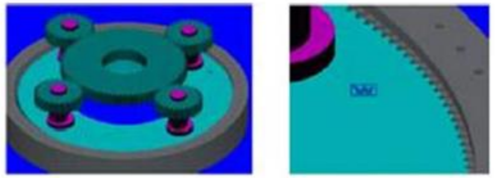

Worm gear

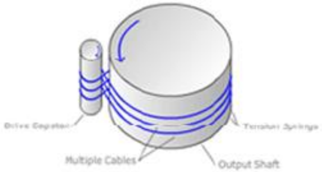

Screw and nut


Rack and pinion


Harmonic drive


Chain and pinion


Planocentric drives


Capstan drive

Big vs. small heliostas

- Big heliostats - few parts and foundations are needed for an equivalent mirror area
- Small heliostats – low wind speeds (low height) and then low weight per mirror area

F. Téllez, M. Burisch, C. Villasente, M. Sánchez, C. Sansom, P. Kirby, P. Turner, C. Caliot, A. Ferriere, C A. Bonanos, C. Papanicolas, A Montenon, R.Monterreal, J. Fernández, 2014. **State of the art in heliostats and definition of specifications – survey for a low cost heliostat development**. STAGE-STE EU Project, Deliverable 12.1.

A. Pfahl, J. Coventry, M. Röger, F. Wolfertstetter, J. F. Vásquez-Arango, F. Gross, M. Arjomandi, P. Schwarzbözl, M. Geiger, Ph. Liedkejk, **Progress in heliostat development**, Solar Energy 152 (2017) 3–37

J. Coventry, J. Campbell, Y. Peng Xue, C. Hall, J.-S. Kim, J. Pye, G. Burgess, D. Lewis, G. Nathan, M. Arjomandi, W. Stein, M. Blanco, J. Barry, M. Doolan, W. Lipinski, A. Beath, **Heliostat Cost Down Scoping Study Final Report** ANU document reference: STG-3261 Rev 01 (2016)

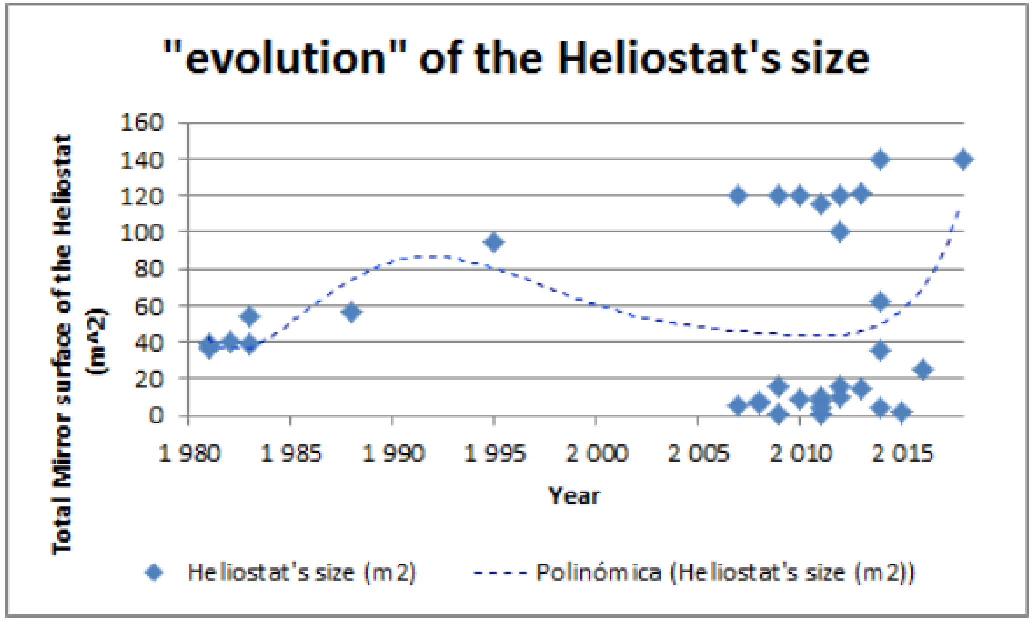


Figure 15. Temporal evolution of the size of the heliostats deployed commercially.

Sener's 178 m2 heliostat with hydraulic drives and concrete pylon

Abengoa ASUP 140

Trends – Titan Tracker

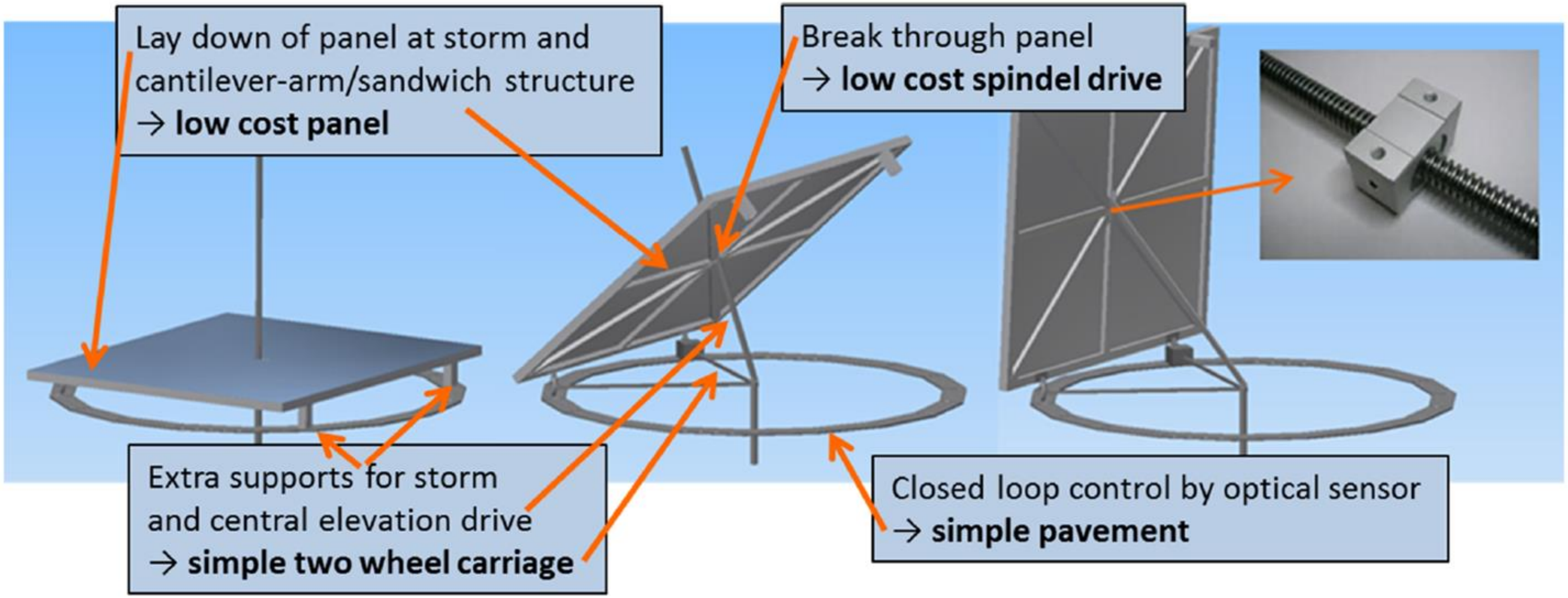
- Heliostat with carousel based azimuth drive
- $150m^2$ - heliostat size
- Carousel design enables cost effective heliostat design
- Gear 3F AC motor.
- Jack – worm gear for elevation
- Lower than 100 €/m^2

N. Goel et al. Energy Procedia, Volume 57, 2014, Pages 301-310

DLR carrousel

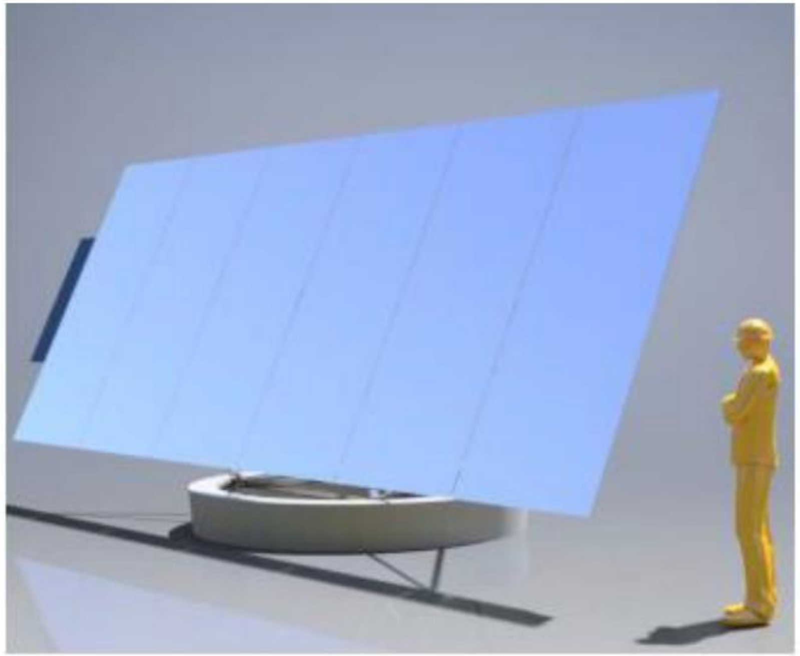
A. Pfahl et al. AIP Conference Proceedings 2033, 040030 (2018)

A. Pfahl et al. AIP Conference Proceedings 2126, 030042 (2019)



Drop-C – SolarDynamics

- Drop-C heliostat
  - Evolution of the Abengoa Solar's Ring-of-Power (ROP) helostat (Colorado office award #EE0003596, Installed cost, 114 \$/m^2)
  - 76 \$/m^2 installed cost estimate
  - Efficient space frame support system
  - Azimuth drive/idler wheels transmit all load to foundations (no central ground anchor required)
  - Ballast foundation
  - Drop-in place installations
  - Reduced civil work, permitting, and geotechnical risk in solar field
- Wireless Mesh Network and Rapid Calibration System

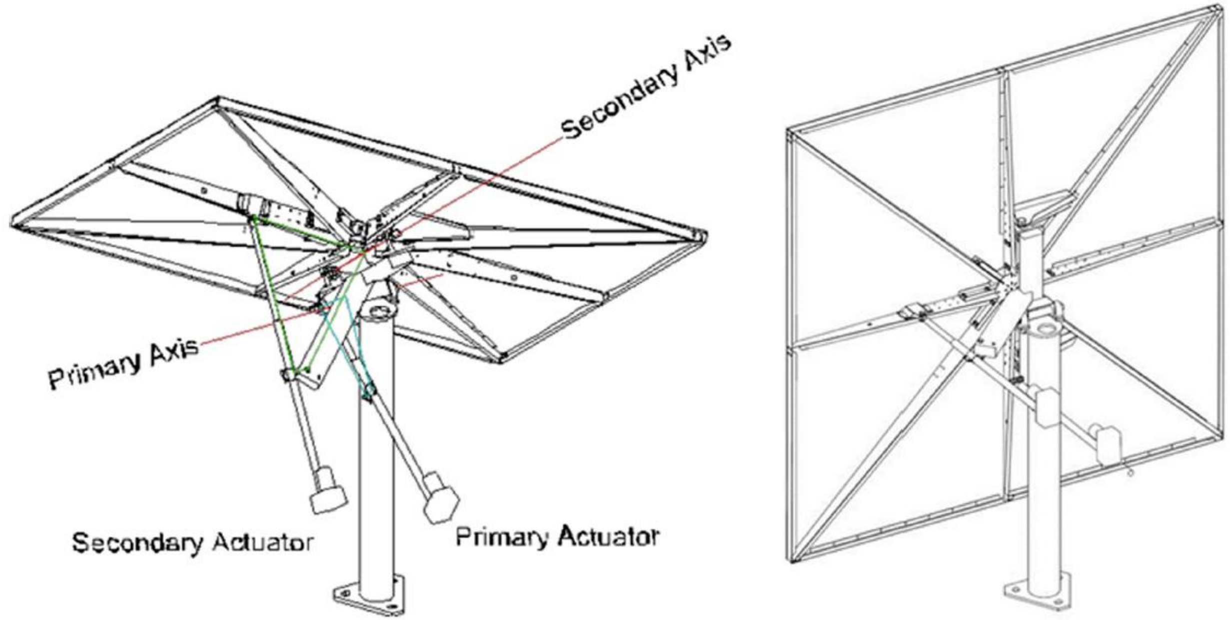


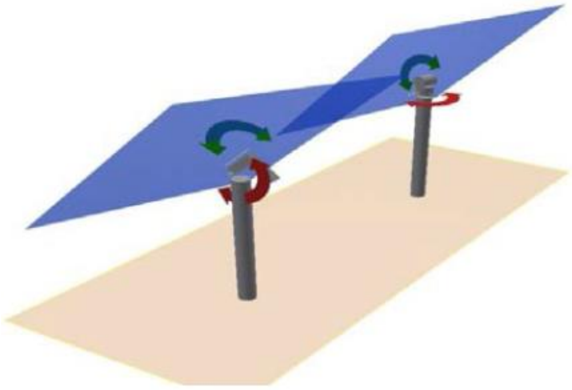
Drop-C: Front View

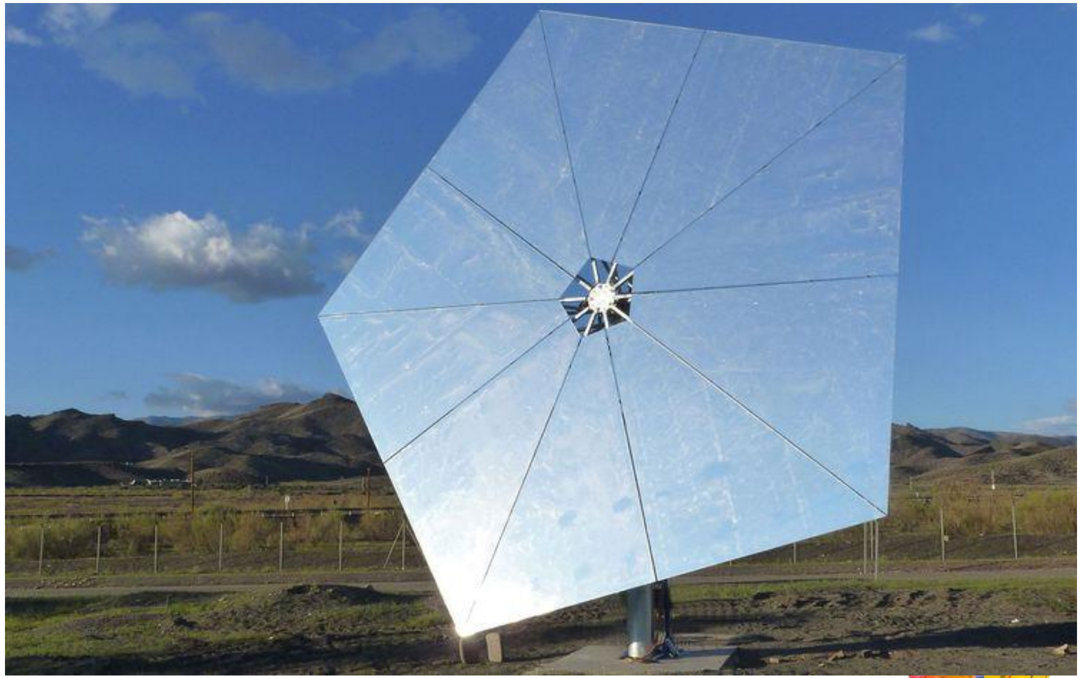
Drop-C Heliostat Key Metrics	
Reflective area	27 m^2
Overall dimensions	8.46 m wide x 3.21 m tall
Aspect ratio	2.6 (width/height)
Stow height	1.98 m
Mirror shape	Flat, no-canting
Foundation	Ballast
Power	PV plus battery
Control	Wireless

CSIRO

- 4.5 m^2 (2.44 m x 1.84 m)
- Linear driven horizontal primary axis







Trends – SBP Stellio

- Schaich Bergermann Partner
- 48 m^2
- Compact round-like form
- Linear drives

F. Arbes et al. AIP Conference Proceedings 1734, 160002 (2016)

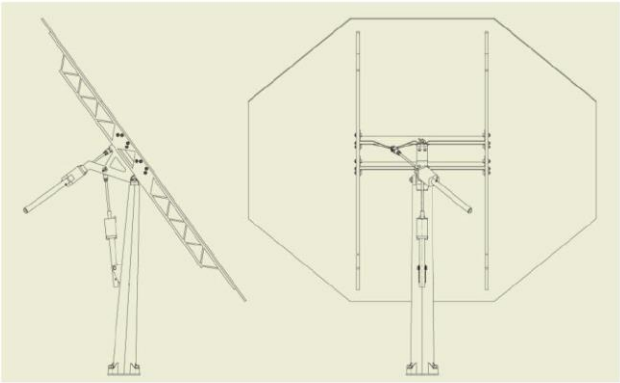
F. von Reeken et al. AIP Conference Proceedings 1734, 160018 (2016)

T. Keck et al. Hami – The first Stellio solar field. AIP Conference Proceedings 2126, 030029 (2019)

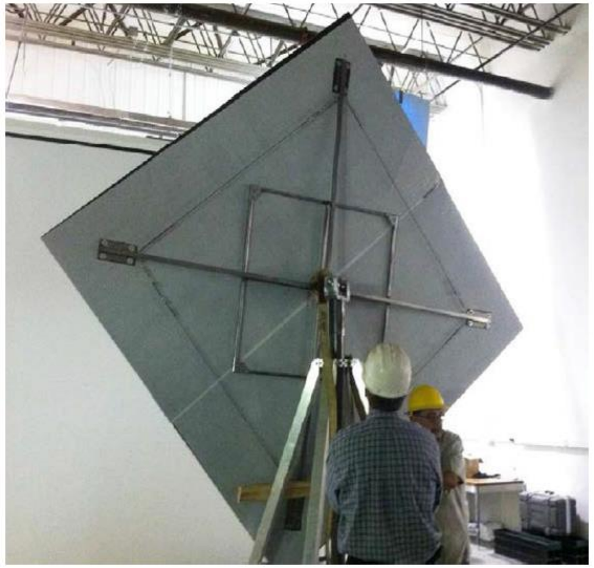
D. Nieffer et al. AIP Conference Proceedings 2126, 030039 (2019)

…and more

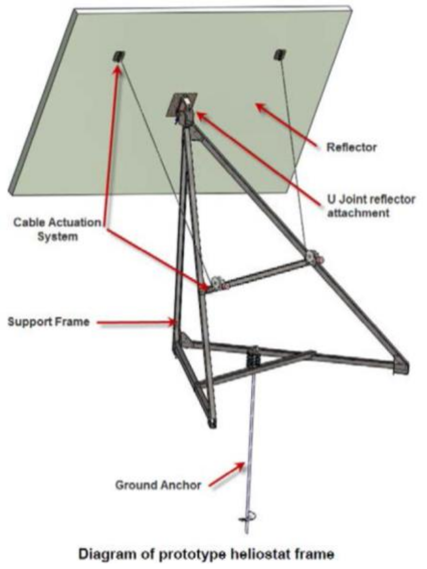
Aora m² heliostat



Heliotower's 36m² heliostat



NREL 6m² heliostat



The Google heliostat

Solaflect's 16 m² 'suspension heliostat'. 16 x 1 m² glass facets held in position by cables tensioned from a compression element perpendicular and central to the mirror panels

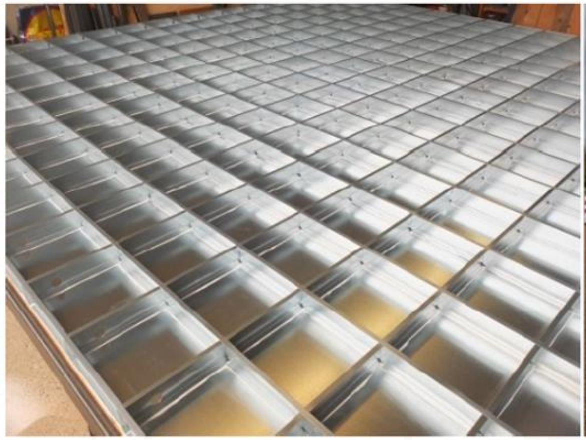
Heliosystems's 9m² "Passive Adjustment Toroidal Heliostat" (PATH),

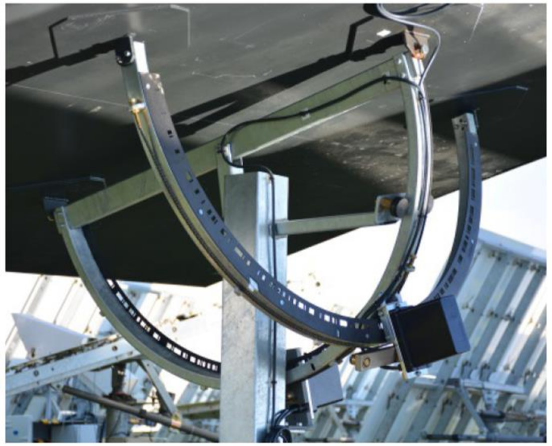
UNAM heliostat

Trends – DLR heliostat

P. Liedke et al. AIP Conference Proceedings 2033, 040021 (2018)

P. Liedke et al. AIP Conference Proceedings 1734, 020014 (2016)

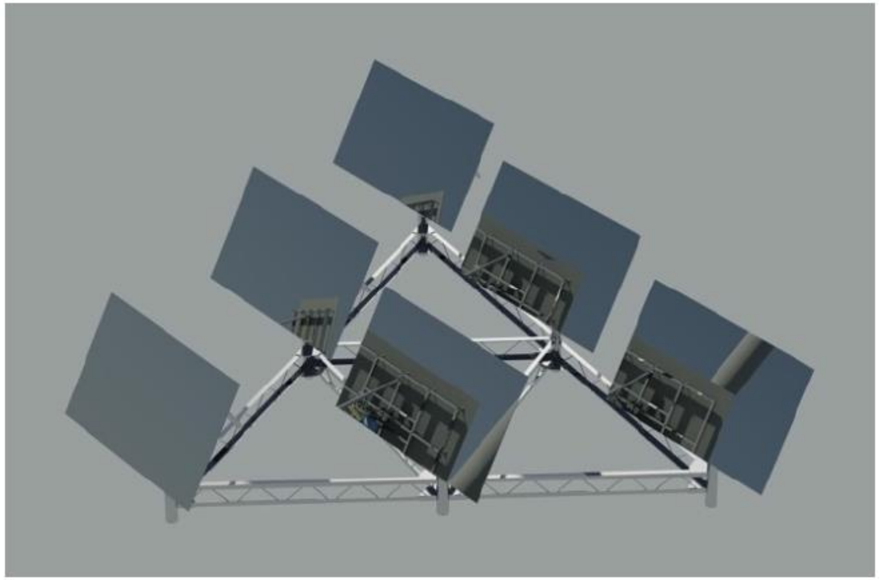


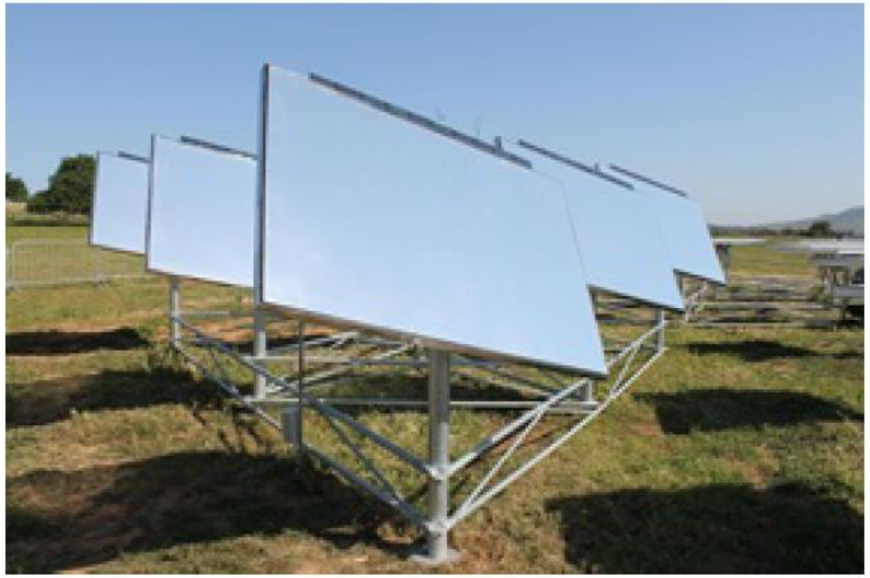


Helio 100

J. N. LarmuthAIP Conference Proceedings 1734, 020013 (2016)

C. –A. Domínguez-Bravo et al. AIP Conference Proceedings 1734, 070006 (2016)





Mini-facets heliostats

- C. Hall. AIP Conference Proceedings 1850, 110005 (2017)

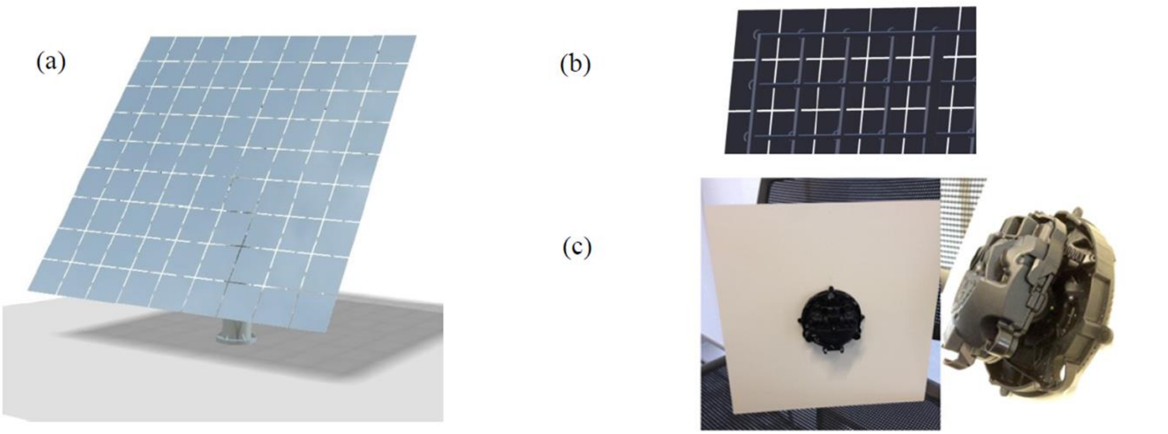


FIGURE 1. (a) Mini-facet concept image. (b) close up of rear. (c) proposed actuator as used in automotive industry mounted to glass mirror panel and close up of the mini-actuator.

Heliostat concepts - Micro heliostats

M. Y. Lazardjani et al. AIP Conference Proceedings 1734, 020028 (2016)

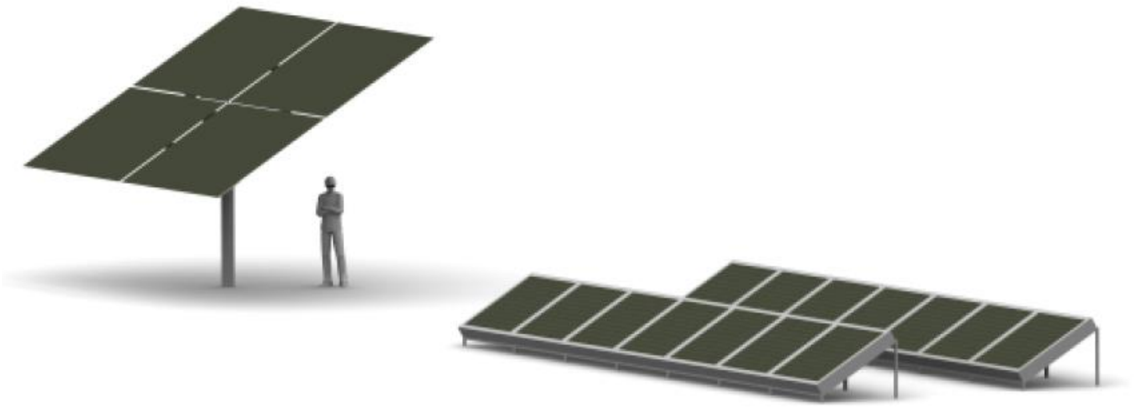
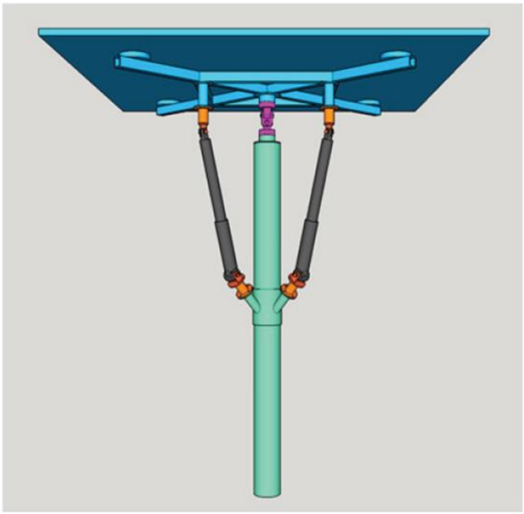


FIGURE 1. Standard heliostat (left), micro-heliostat (MH) (right)

Pitch-Roll heliostats

- Amrita University, India
- The pitch/roll heliostat is particularly well suited to smaller designs which can use very low-cost electric linear actuators produced in large quantities for a wide variety of operations and purposes around the world.
- The primary disadvantage of the pitch/roll heliostat is the significantly more complicated kinematics of such a structure.

J. Freeman. AIP Conference Proceedings 1850, 030018 (2017)



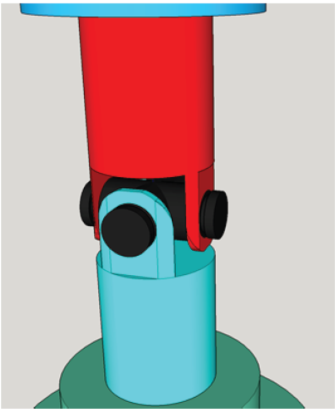


FIGURE 2. CAD model of the simple Hooke's joint, with co-incident axes of rotation

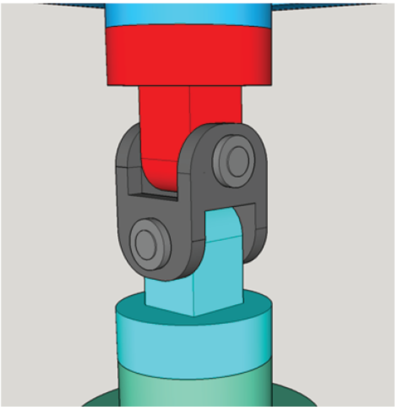
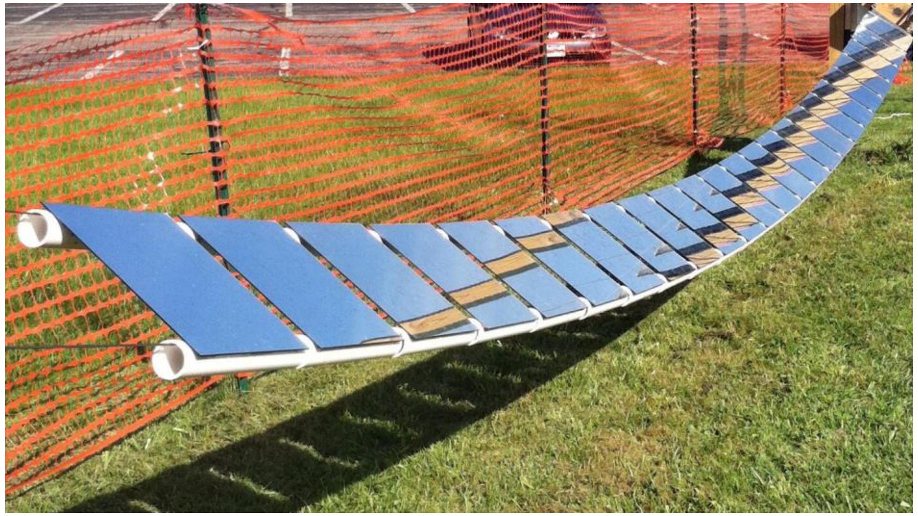


FIGURE 3. CAD model of a modified Hooke's joint with non-zero distance between pivot axes



Heliostat concepts – Ganged heliostats

- Multiple heliostats are combined where they share structures and components, particularly pedestals and rotational drives. These ganged heliostats can be connected via two or more tensioned cabling systems to facilitate structural rigidity and actuation.
- The reduced number of pedestals and drives can reduce the overall cost since these make up the majority of the heliostat cost at approximately 40-50%.
- Challenges for ganged heliostats, which can vary in cabling designs, include oscillation and vibration affects from wind loads that can detrimentally impact performance as well as causing structural damage at particular resonant frequencies.
- 75 $/m^2$

K. M. Armijo. AIP Conference Proceedings 2126, 060001 (2019)

J. Yellowhair et al. Mechanical and Optical Performance Evaluation of the Skysun Tensile Ganged Heliostat Concept. SAND2017-7101 (2017)

Trends - Stamping

- **Stamping** is attractive as a low-cost and scalable manufacturing method, enabling simple fabrication of the support structure of mirror facets. The mirror and support are bonded together on a mould to fix the desired curvature. Stamped facets efficiently use thin sheet metal to form a high-stiffness geometry. This constrains mirror deformation to achieve high optical accuracy.
- Topography optimisation is a promising tool for the design of lightweight stamped mirror facets.
- Concepts optimised for a severe wind load showed the best performance, with distinct bead structures that maximised facet stiffness compared to the finer structures optimised for the evenly-distributed gravity load. Survival during severe winds limits weight reduction, with low gravity-induced shape errors observed at minimum thicknesses to prevent failure.
- Results suggest optimising for minimum weight and evenly-distributed support stress during severe winds is a promising approach for facet design.
- Incremental sheet forming was used to develop a rapid-prototyping method which is accessible and low-cost. The
- ISF process imposes additional geometry constraints, exhibits wall-thinning, and has lower dimensional accuracy compared to stamping.
- Incremental forming may offer a low-cost solution for pilot-scale plants or small run heliostat installations.

N. Rumsey-Hill et al. AIP Conference Proceedings 2126, 030048 (2019);

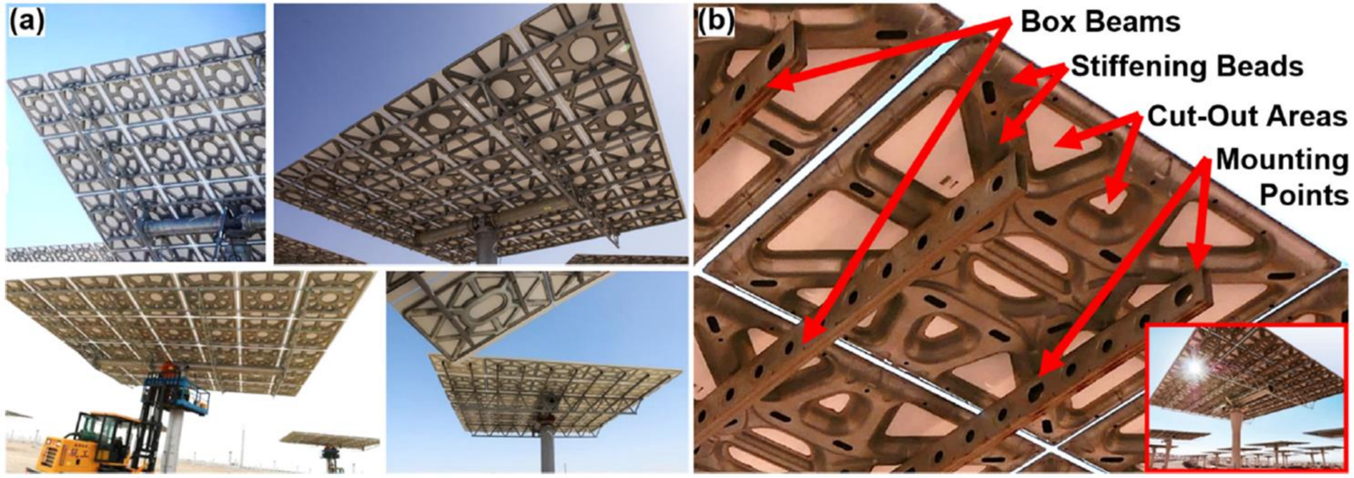
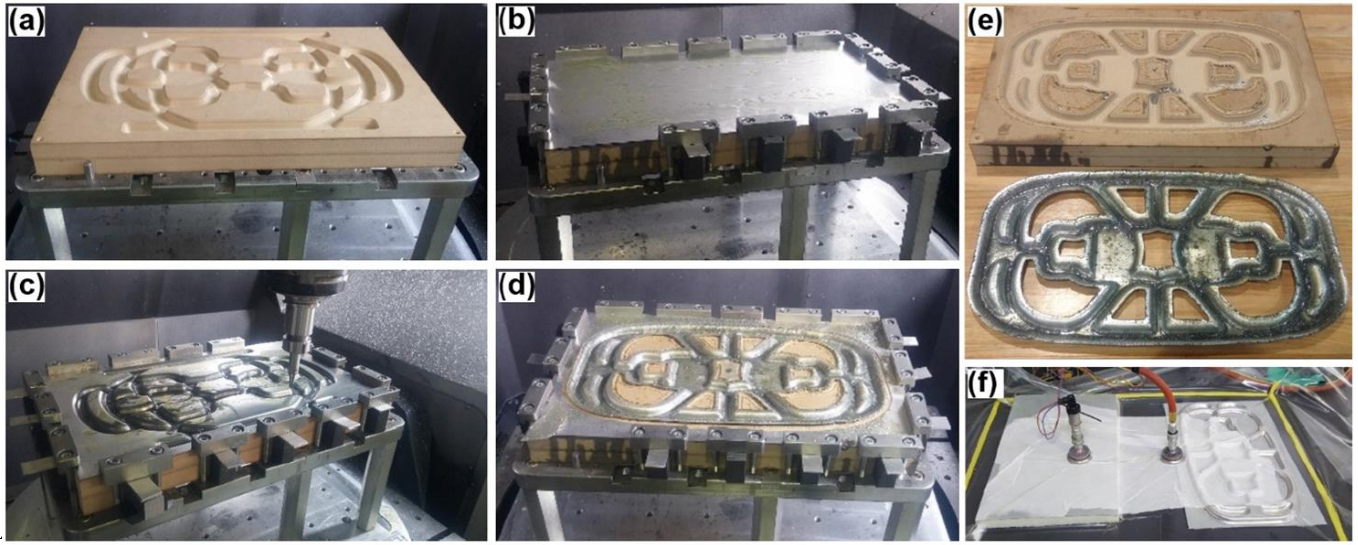


FIGURE 1. (a) Commercial multi-facet heliostats with stamped facets. Clockwise from top left; Crescent Dunes [6], Gemasolar [7], Dunhuang [8], and Suncan CSP plants [9]. (b) NOOR III heliostat incorporating stamped mirror supports [10].



Conclusions

- Heliostat technology is currently considered mature (beam quality smaller than 2.9 mrad, 20-years durability)
- Main target focuses on cost reduction
- “Any clever solution (even if crazy) is a cheap solution”
- No preferencial size: low (1-5 m^2), medium (40-50 m^2) and large (120-180 m^2) heliostats coexist
- Any new technological advance is rapidly implemented in helistotat technology (material, hardware, software)

Thanks for your attention