Node 1: Capital Cost Reduction

ASTRI Symposium on The Future of Concentrating Solar Thermal Technology

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Overview

- Node objectives
- Node rationale
- P11
- P12
- Summary

(P11, P12:)

- Objectives
- Research Streams
- Related efforts
- Future work

Objectives

Node 1 **Capital Cost Reduction**

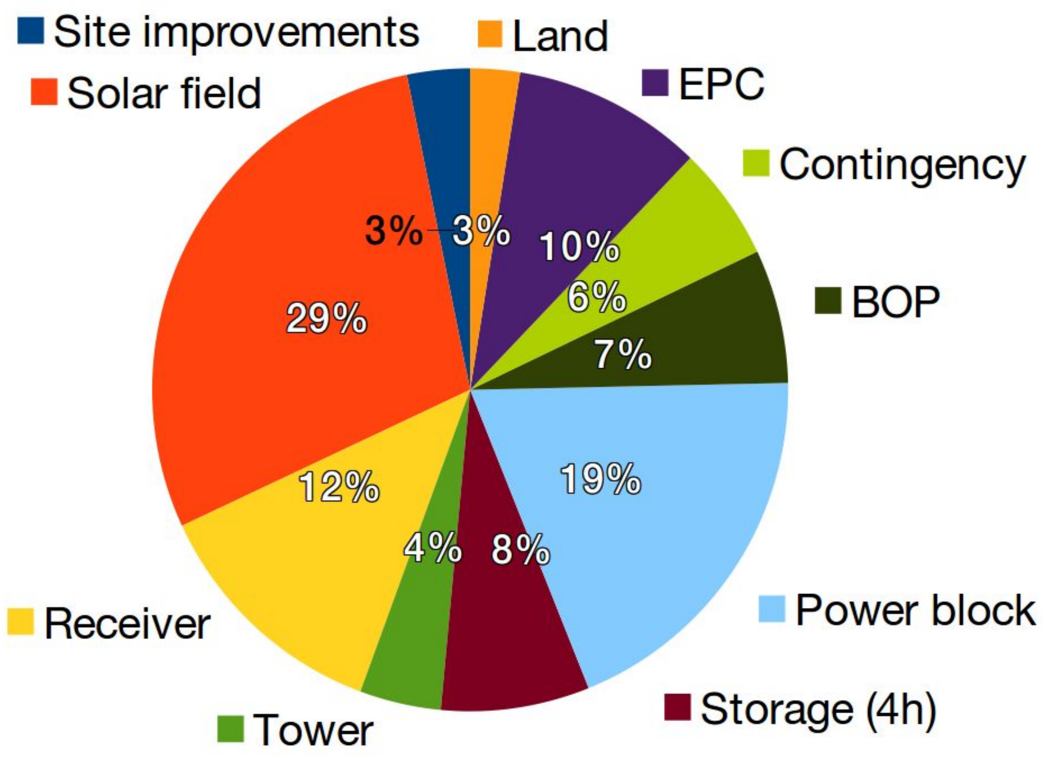
Cheaper components

Raise efficiency: less heliostats

	Y0	Y4	Y8
KPI 13 Capex (AUD*)	738M →	627M (↓15%) →	443M (↓40%)
KPI 11 LCOE (AUD/kWhe)	26.5 ¢ →	19.5 ¢ (↓26%) →	12 ¢ (↓55%)

*costs relative to the ASTRI central tower reference case (AUD2012)

Plus non-technical KPIs on collaboration, publication, etc.



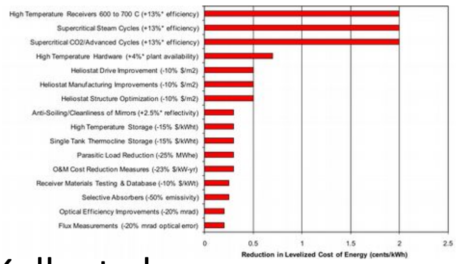
'Config 0' Beath/Aghaeimeybodi

- Scope was narrowed to central tower systems only

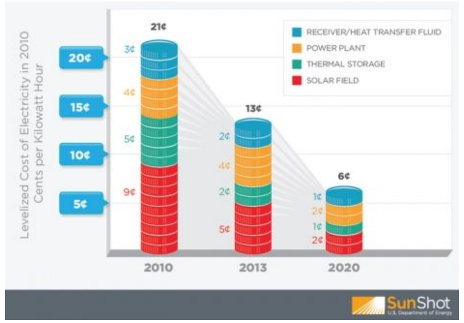
Rationale

- Kolb et al (2011) Power Tower Technology Roadmap
  - high-T receivers 600–700°C: +13% efficiency – save 2 ¢USD/kWhe
  - heliostat drive, manufacturing, structure, optical efficiency, flux measurement – save 2.3 ¢USD/kWhe
- A.T. Kearney (2010)
  - Heliostat size and structure, cost-optimised tracking (total, 18-22% of LCOE)
  - Field layout, multi-tower, high-temperature receivers (save 10-15% of LCOE)
- Sunshot (2010)
  - Demanding aggressive cost reductions from 21 ¢USD to 6 ¢USD by 2020
- ECOSTAR (2005)
  - heliostat size and structure – save 7-11% of LCOE
  - advanced mirrors – save 2-6% of LCOE
  - increased receiver performance – save 3-7% of LCOE

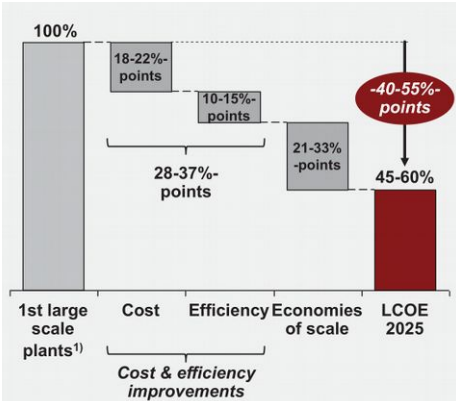
Independently-conducted studies before ASTRI indicated strong potential cost savings for CSP (-40% of LCOE) from heliostat field cost reduction and receiver efficiency.



Kolb et al



Sunshot



A.T. Kearney

Two projects

- Project P11: **Heliostat Field Cost Down** Project
- Project P12: **Receiver Performance** Project

P11: Heliostat Field Cost Down Project

- Objective: **proof of concept for a new low-cost heliostat** 120 AUD/m² (stretch target 90 AUD/m²)
  - a 46% reduction compared to baseline field cost
  - results in 17% reduction in overall system capex
- **Product development** approach guides our topics
- Technical streams goes deep
  but also produces **portable results**

ASTRI partners ANU, Flinders, UA, UniSA, QUT, CSIRO

120 AUD ≈ 93 USD ≈ 82 EUR
90 AUD ≈ 70 USD ≈ 62 EUR

Product development approach

B. 30 m² sandwich panel heliostat
(thin glass or film mirror, sandwich panel, tuned curvature, few facets, little support structure, shock absorbers, wind-load reducing features, autonomous)

D. Drop-in heliostat
(prefabricated, autonomous, mass-based foundation, simple installation)

C. Mini-facet heliostat
(small plastic mirror facets mounted on 'coarse' tracking heliostat frame, small actuators, active focusing)

Technical streams

E. Mirror facet development
Glass/metal and plastic/composite sandwich

F. Aerodynamics and wind loads

G. Manufacturing systems

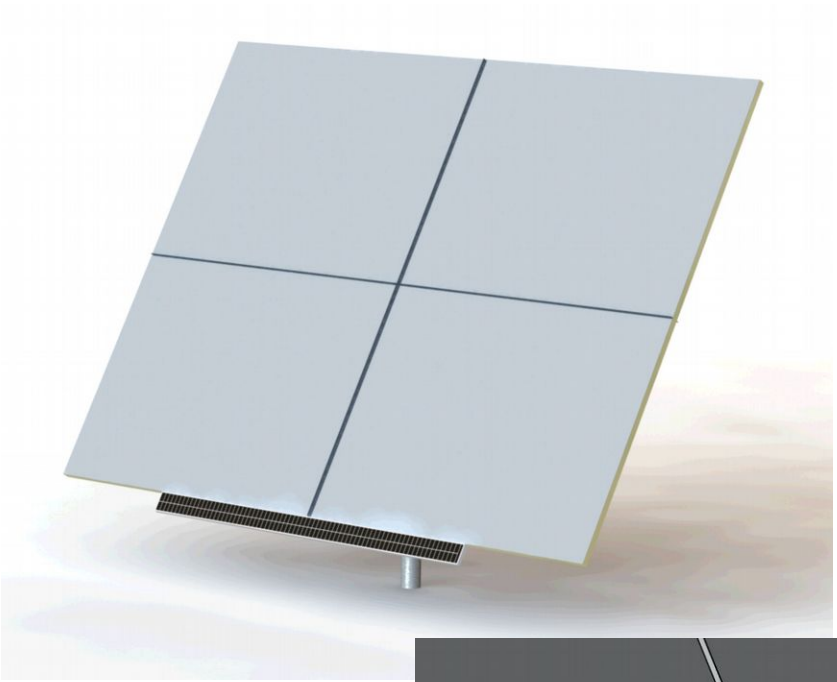
H. Design and testing tools

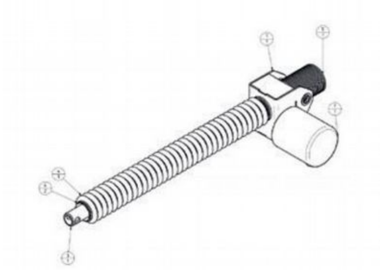
I. O&M systems
Holistic design incorporating cleaning

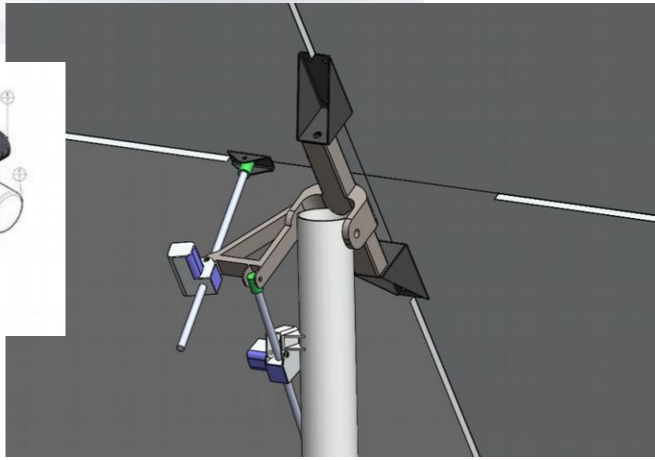
J. Heliostat field optimisation

P11: 30 m² sandwich panel heliostat

- Concept:
  - Structurally integrated sandwich panels
  - 30 m², four facets joined at edges
  - COTS, delivery/assembly installation logistics
- Integrated structural/optical analysis conducted; design iteration underway
- Costing analysis: 116 AUD/m², on track to meet cost target.



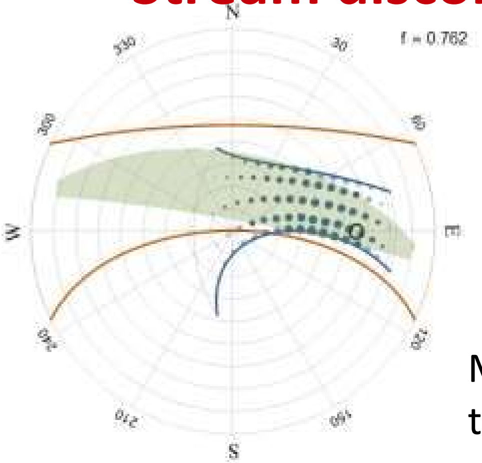




Company: APC

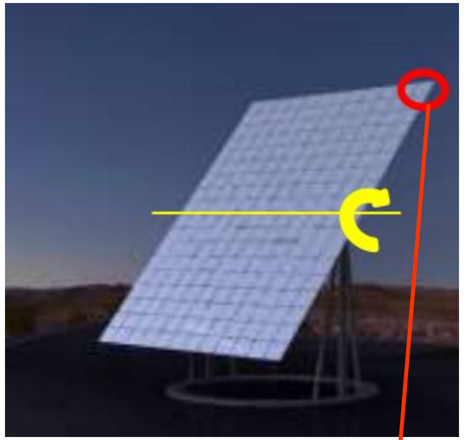
P11: Mini-facet heliostat

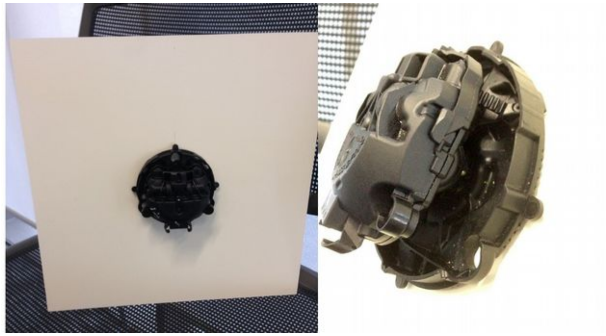
- Optical/astigmatism benefits considered attractive, but not quantified.
- Injection-moulded facets and front-surface coatings considered.
- Cost: approx +16 AUD/m² relative to reference design.
- **Stream discontinued**



Modelling of tracking extents

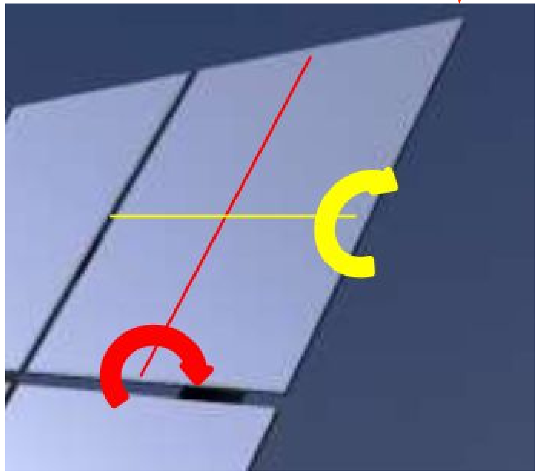
Heliostat-level tracking





Mirror actuators from automotive industry: $5 ea.

Company: SMR



Facet-level tracking: would reduce astigmatism for better optical performance, could permit one axis of heliostat-level tracking to be eliminated.

P11: Drop-in heliostat

- Concept for rapid (~30 min) installation in the field:
  - 12-16 m^2 with three-four facets
  - Concrete-free non-displacement pile footings (SureFoot)
  - GPS and accelerometer sensing for initial placement/alignment and close-loop tracking
- Progress:
  - Current cost estimate is a little high; methodology being refined.
  - Optical and CFD analysis of novel shape, patenting in process.

Initial concept. Current concept has evolved significantly and patenting is being pursued.

Company: SureFoot

P11: Mirror facet development

- Sandwich-panel facets need low-cost materials, 1 mrad optics, high strength, low-cost manufacturing process.
- Core materials down-selected to
  - Aluminium honeycomb facets: built and tested, results encouraging. Cost ~5 AUD/m².
  - Polyurethane: will build with help of APC Pty Ltd, testing planned. Cost ~10 AUD/m² or less.
- Photogrammetry, finite element analysis and ray-tracing analysis of whole panels under way.

Sandwich panel heliostats offer the prospect to reduce material use in conventional heliostats, saving cost.

Aluminium honeycomb facet

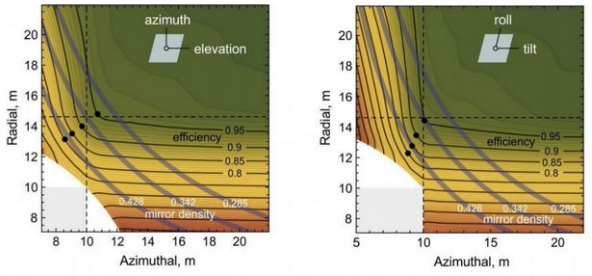
Sample of APC Polyurethane panel

Photogrammetry

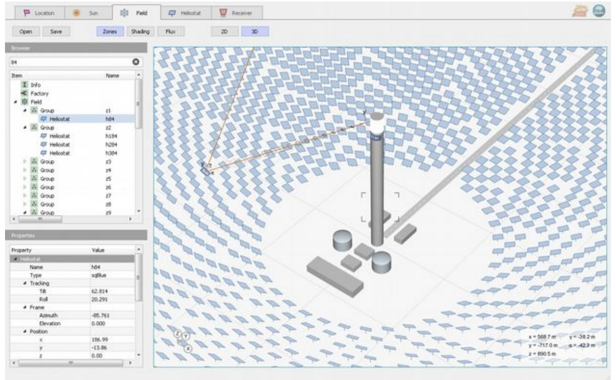
P11: Heliostat field optimisation

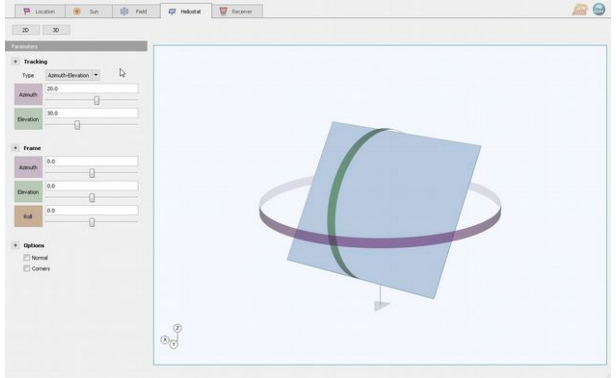
- Raytracing and cone optics models of heliostat fields
- Three key aims:
  - Optimised field layouts
  - Decision support for cost/performance trade-offs
  - Support for receiver design efforts
- Open-source software including *Tonatiuh* rapidly being adopted by many groups in CSP community.

Accurate modelling of CST optics is critical to any system-level cost reduction effort. Optical modelling in ASTRI is linked with work in P12, P42, P21 and P41.



Annual visibility as a function of azimuthal and radial separations for azimuth-elevation (L) and tilt-roll tracking (R)

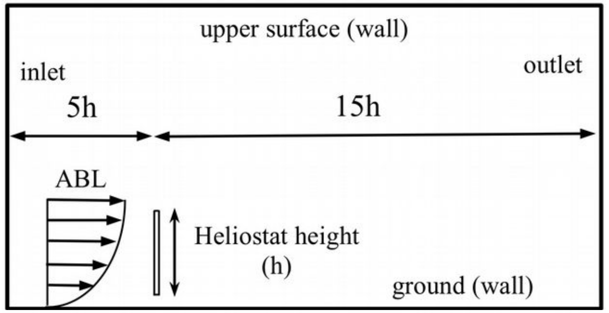




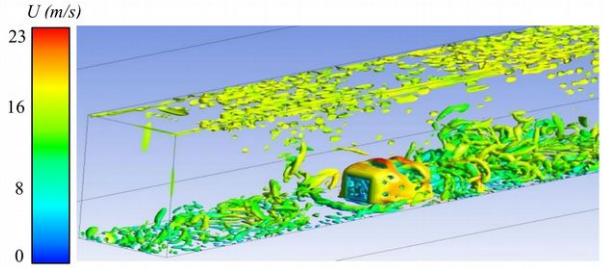
P11: Aerodynamics and wind loads

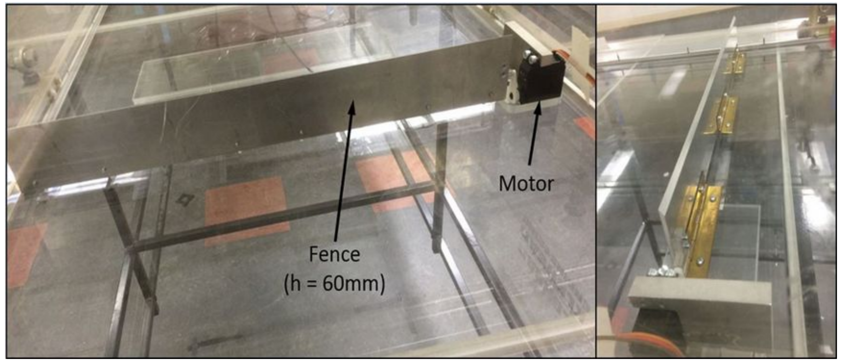
Tighter quantitative understanding of wind loads → More optimised designs
Reduced safety factors
Lower-cost heliostats

- Major effects of gusting and turbulence
- Wind tunnel testing facility
- Numerical modelling (CFD: ELES)
- Review/review state-of-art correlations



Embedded large-eddy simulation (ELES)





Testing large-scale turbulence structures

Characterising wind-induced pressure distributions on a scaled-down heliostat

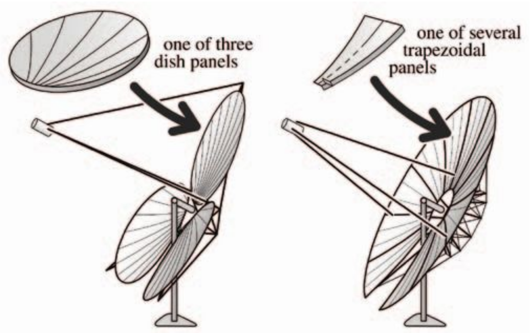
P11: Related efforts, future work

Future work, now to Y8

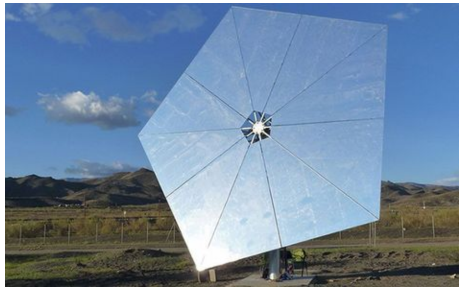
- Down-select to a single concept
- Wind loads in heliostat fields
- Aerodynamic optimisation and dynamic loads
- Multiple prototyping iterating
  (TRL 6-7 if possible)
- Integrated structural/optical modelling
- Linking with industry for manufacturability studies

ASTRI points of difference:
Structurally-integrated sandwich panels, strong focus on wind loads, novel controls and setup, optimised sizing for Australian context.

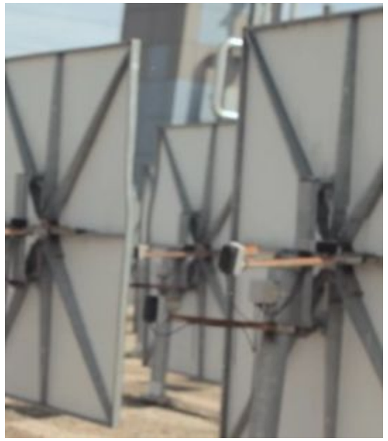
Some related efforts on low-cost heliostats



JPL film-on-foam



Stellio glass-on-frame



CSIRO radial ribs, single facet

Stellenbosch 'plonkable' module

P11: Summary

- Two concepts for low-cost heliostats currently in development.
  - 30 m² sandwich panel heliostat
  - Drop-in heliostat
  - On track for cost target of 120 AUD/m².

Down-selection/merging intended

- Tools for modelling and analysis have advanced in parallel.
  - Sandwich panel facets: lighter-weight panels
  - Field layouts: increased optical efficiency
  - Wind loads: reduced structural redundancy
- Impact will be a 17% capex reduction, key contribution to 12 cAUD/kWh target.

P12: Receiver Performance Project

Participants: ANU, UA, CSIRO, Flinders, UQ, Sandia

Objectives

- Based on ASTRI scoping study, decision was to focus on
  - Tubular sodium receivers
  - High-efficiency particle receivers

	Efficiency*	T_{out}
Tubular receiver	**≥91%**	≥700°C
Particle receiver	**≥85%**	≥800°C

*Design point efficiency

Three concepts in development:

'FONaR' sodium receiver

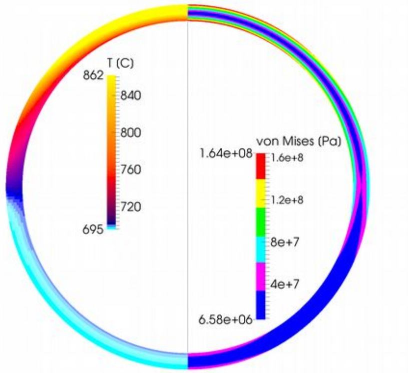
Falling particle receiver

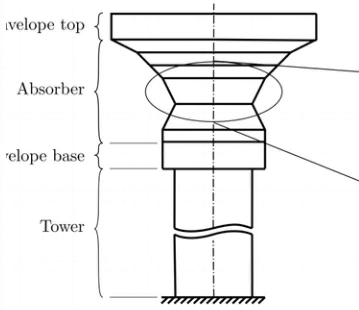
Solar expanding vortex receiver

P12: 'FONaR' sodium receiver

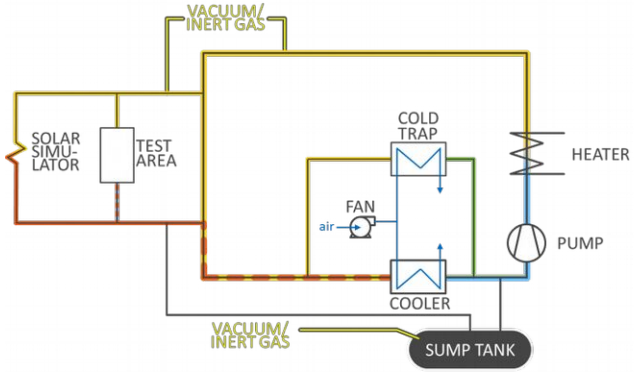
- Achieving <u>91% at 700°C with sodium</u> will represent a working temperature well higher than that demonstrated elsewhere.
  - Thermo-plastic stress analysis of receiver tubes
  - Multi-objective optimisation of a thermal/optical model with varying geometry: *flux optimised*
  - Developing/installing new sodium lab facilities, for eventual solar simulator testing
- Current model: <u>88%</u> (convex)

Sodium, as a high-conductivity liquid for heat transfer, offers the strong potential to move beyond temperature and efficiency limits that state-of-the-art molten salt receivers are subjected to.



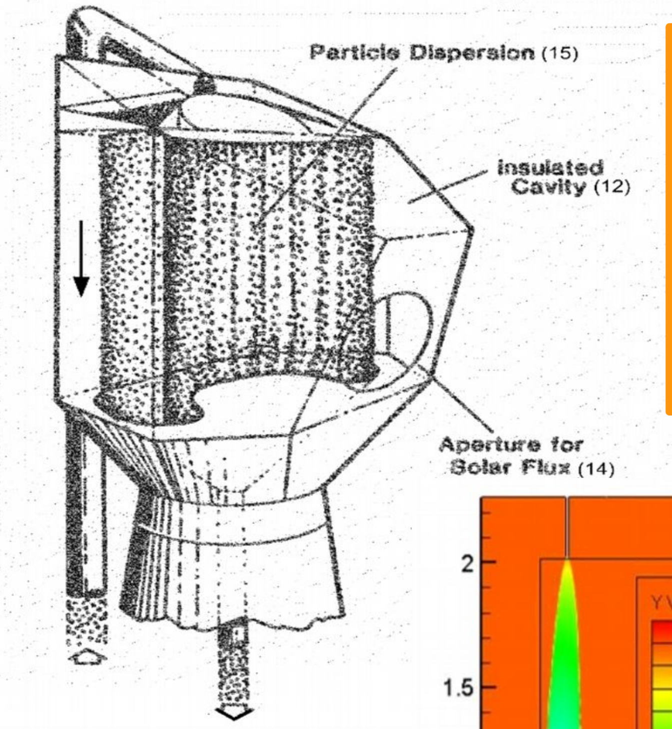


Companies:
CMI, VastSolar



P12: Falling particle receiver

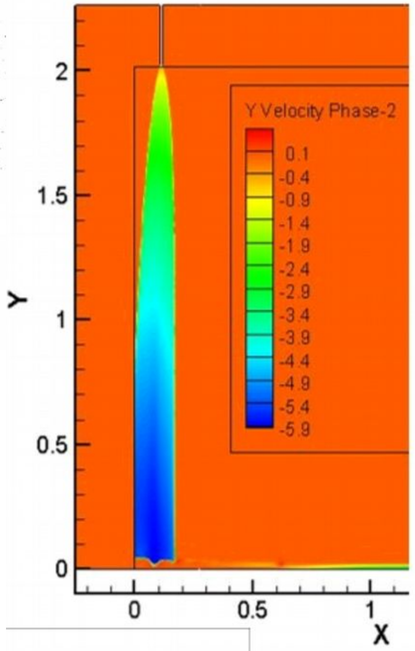
- Novel falling particle receiver currently being patented (in collaboration with Sandia)
- Current modelling gives 89% efficiency at summer noon. **On track for efficiency target.**
- Computational fluid dynamics (CFD) modelling
- Ray-tracing combined with analysis based on radiative transmissivity in order to assess receiver efficiency as a function of particle size and flow rate
- Experimental tests currently being prepared



(Prior Art)

Fig. 1

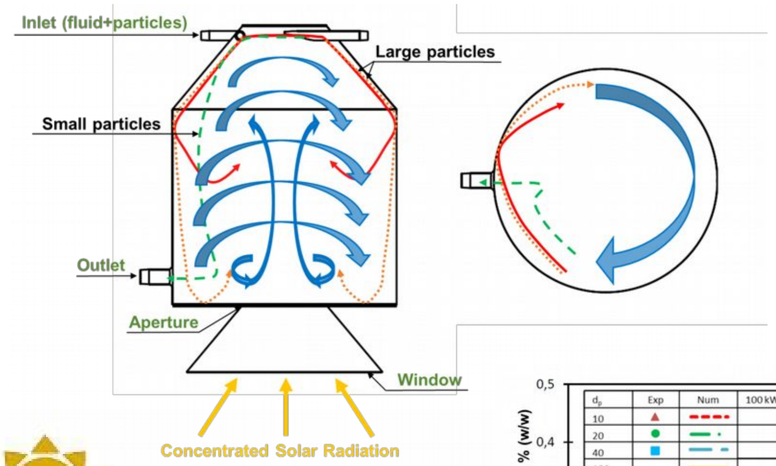
Particle receivers offer direct absorption of solar flux and may unlock much higher temperatures and efficiencies, if particle loss and stability issues can be addressed.

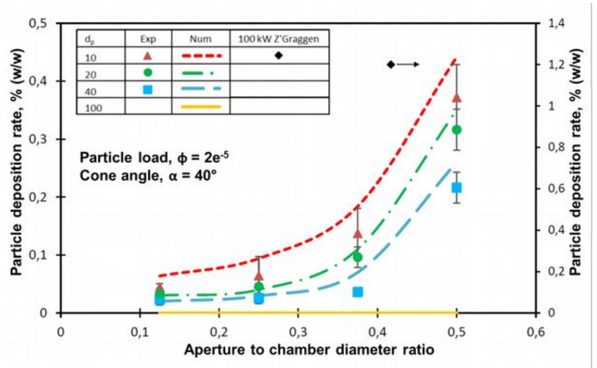


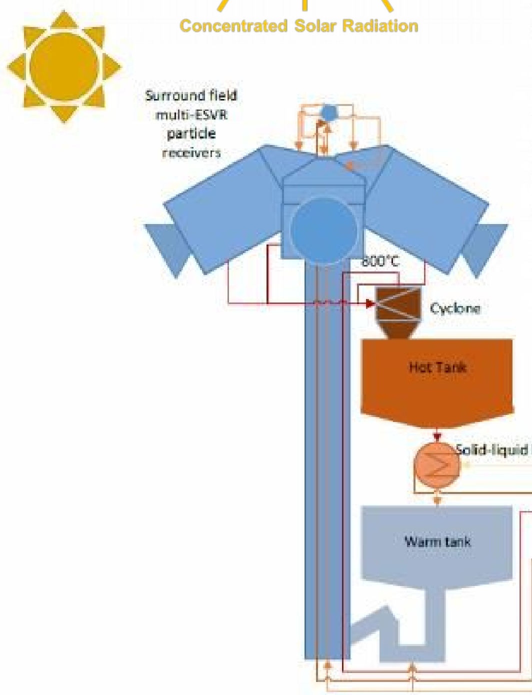
P12: Solar Expanding Vortex Receiver (SEVR)

- Cyclone-like particle cloud in a cavity
  - Flow field configured to reduce deposition on the window, or may allow elimination of the window entirely.
  - Residence times tuned well to particle sinze (larger particles remain in flux for longer, more uniform temperatures)
- Selection of particles underway in common with falling particle effort
- CFD and experimental work

SEVR concept offers potential for a high-efficiency windowless receiver with uniformly heated particles







P12: Related efforts, future work

Future work now – Y8

- Develop 2 MW/m^2 receivers meeting the efficiency targets to point where ready for scale-up
  - High-accuracy models validated through experiments
  - Prototyping and de-risking
  - Full energy and annual performance analysis for system-level cost/efficiency impact
  - Materials selection and corrosion issues
  - Parametric and optimisation studies

Related efforts

- Vast Solar
  - Experimental facility
  - Related ARC project with ANU on sodium boiler
- DLR, Sandia, ETH work on particle receivers
- KIT work on liquid metals/sodium

P12: Summary

- Tubular and particle receiver concepts exist that meet project efficiency targets
- Key technical areas
  - Computational models including CFD and ray-tracing
  - Thermal stresses in high-temperature sodium tubes
  - Radiative heat transfer in particle receivers
  - Material selection
  - Multi-objective receiver design optimisation
- New experimental facilities

Node 1: Summary

- Focussed topics arising from scoping studies conducted early in Y1-4.
- **Low-cost heliostats**
  - Novel concepts for heliostat cost reduction, 120 AUD/m^2
  - High-quality analysis and tools to allow evaluation and optimisation
- **High-efficiency receivers**
  - Particle (85%, 800°C) and sodium receivers (91%, 700°C) on track to meet targets
  - CFD and optical analysis advancing strongly for all concepts
- Patenting in progress in several areas, increasing links with industry
- Need to prove concepts, increase TRL, prove that fully integrated systems can deliver the LCOE target.

Acknowledgements

ARENA

Australian Government

Australian Renewable Energy Agency

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CSIRO

Australian National University

The University of Queensland Australia

The University of Adelaide

University of South Australia

QUT

Flinders University

Extra slides

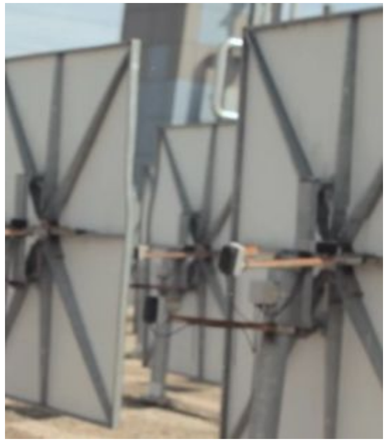
Node 1: related ARENA projects

- CSIRO heliostat, HeliostatSA
- Vast Solar 6 MW pilot
- ANU bladed receivers
- ANU cavity receiver
- ANU MnOx – optical modelling for a high-T receiver concept
- MUSIC
- Recent CSP feasibility studies (Perejori, Collinsville, Port Augusta)
- UA Solar alumina project?
- UNSW scale-up thermochemical reactors

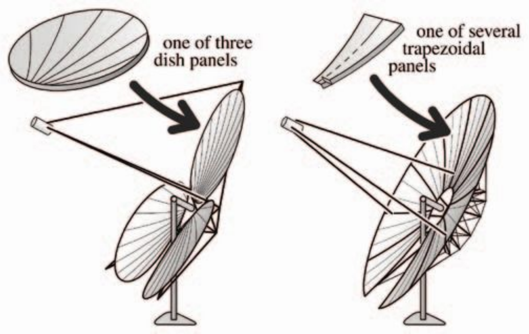
Related heliostat projects

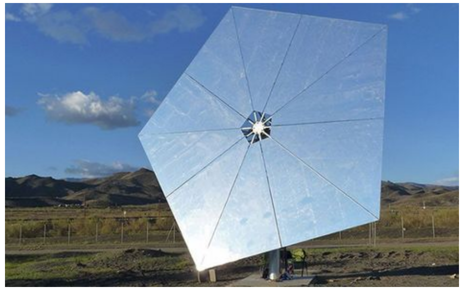
- CSIRO heliostat/HeliostatSA
- SBP Stelio
- DLR Pfahl 'rim drive'
- Abengoa Khi Solar 1 sandwich
- Stellenbosch 'plonkables'
- Heliosystems
- Aalborg/eSolar
- JPL 'film on foam'

Related efforts



CSIRO





Stellio