ASTRI
AUSTRALIAN SOLAR THERMAL RESEARCH INITIATIVE

ASTRI Overview

ASTRI 2015 Annual Workshop

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11 February 2015

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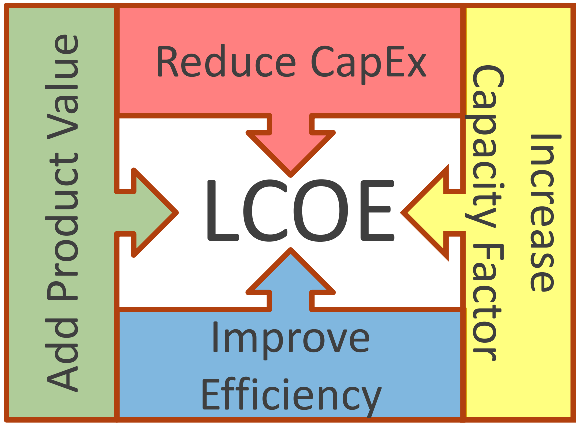
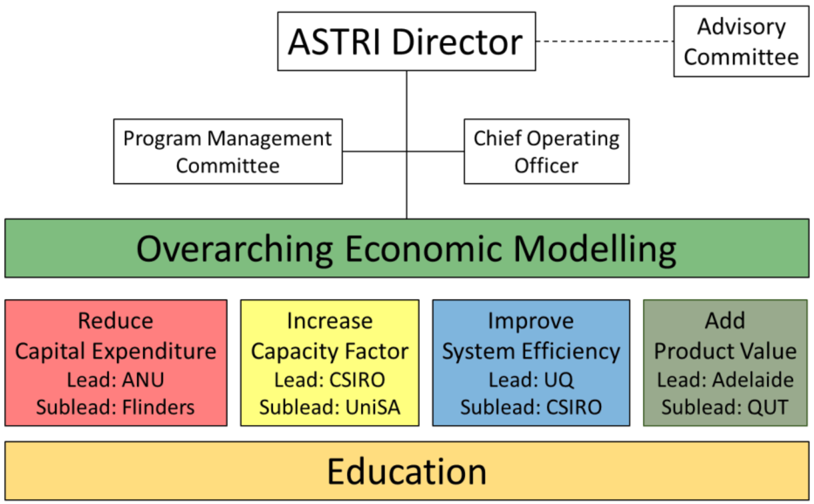
- ASTRI Overview
- Relevance of CST
- Trends and priorities in CST research
- Technologies that ASTRI will deliver
- How Australia will benefit from ASTRI
- The need for a System Approach
- Concluding remarks

Australian Solar Thermal Research Initiative

ASTRI is committed to demonstrating a pathway for reduction in LCOE of CSP plants, targeting 20 c/kWh in Year 3 and 12c/kWh by 2020 whilst providing dispatchable firm supply



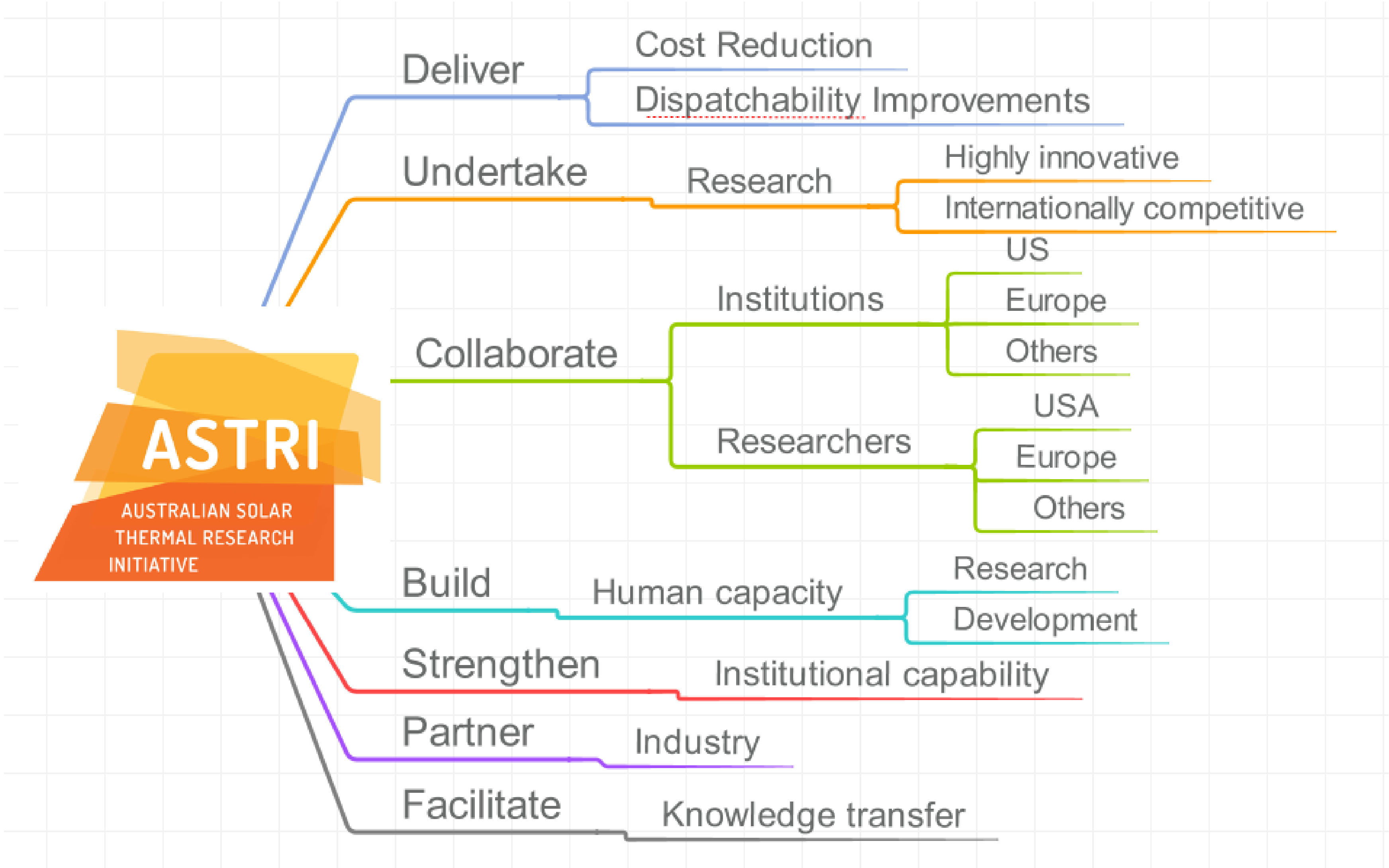


- Budget: $87m
  - ARENA $35m
  - Partners $46m
  - Industry $6m

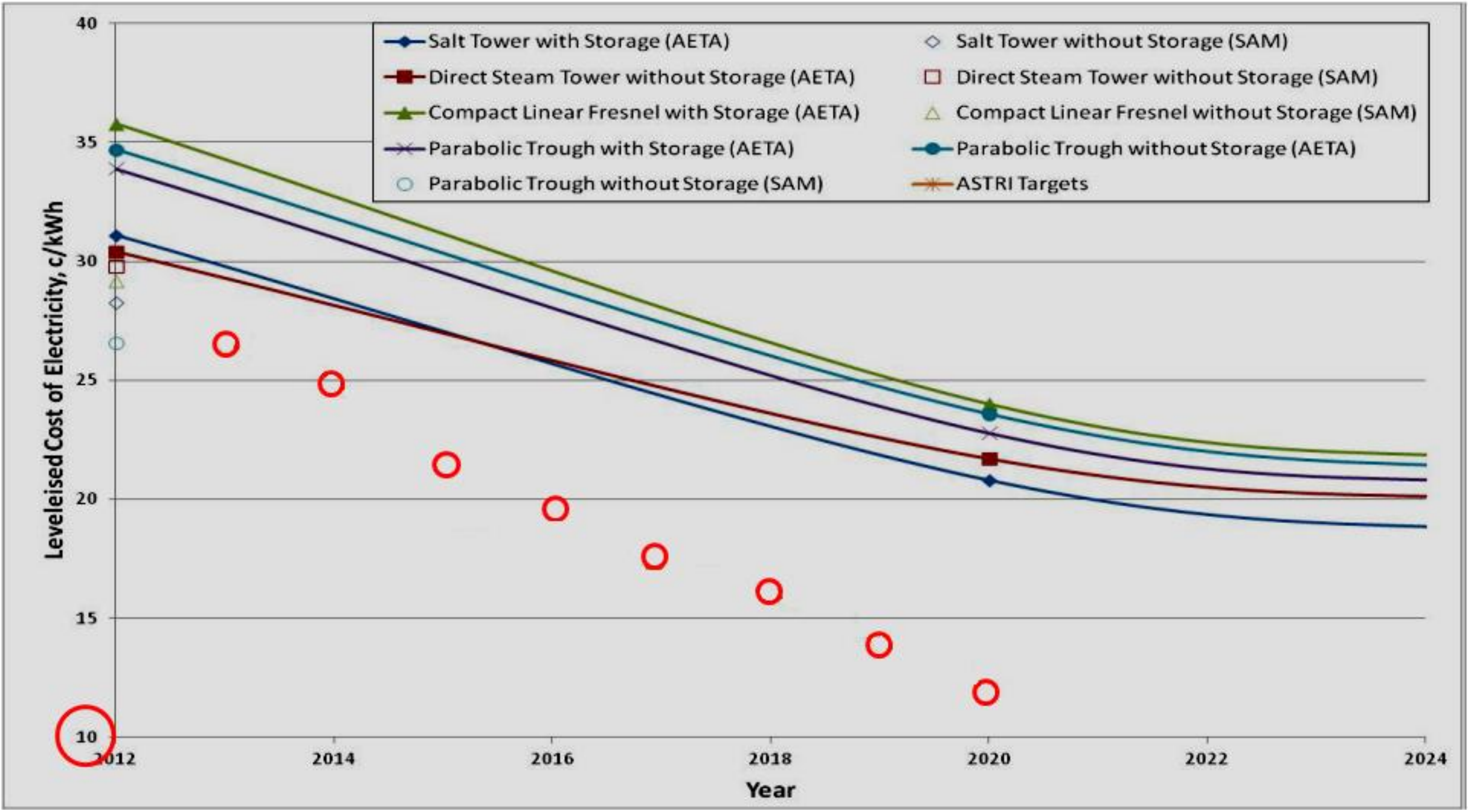
ARENA
Australian Government
Australian Renewable Energy Agency

- Program 8 years (2013-2020)
  - with critical review in Year 4 (2016)
- Overarching Economic Modelling
- Research Nodes
  - Reduce CapEx
  - Increase capacity factor
  - Improve efficiency
  - Add Product Value
- Education Program

ASTRI Objectives



ASTRI LCOE Targets



Key Performance Indicators (KPIs)

		2013	2014	2015	2016	2017	2018	2019	2020	
KPI	ASTRI Objective and KPI	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Total
	Research Quality									
1	Number of refereed journal publications	3	7	10	15	15	20	22	28	120
2	Percentage of joint refereed journal publications	0%	10%	15%	20%	22%	25%	28%	30%	
	US Collaboration									
3	Visits to/from US Collaborators	5	5	5	5	7	9	11	12	59
4	Number of new projects started with US institutions	0	1	3	5	4	4	4	4	25
	Human Capacity									
5	Accumulative number of new staff/postdocs/PhDs recruited	8	18	30	42	55	65	75	80	80
6	Accumulative number of post-graduate student completions [b]	0	0	0	4	12	20	28	44	44
	Collaboration involving research training									
7	Number of student/staff visits between partner institutions	20	20	20	20	20	20	20	20	160
	Industry Engagement									
8	Funding from external sources ($k)	$0	$200	$250	$300	$500	$800	$1,200	$2,000	$5,250
	Knowledge Transfer									
9	Number of conference presentations	3	5	7	10	12	15	18	22	92
	Financial									
10	Accumulative In-kind contributed ($k)	$2,249	$6,249	$10,613	$15,138	$19,432	$25,448	$31,184	$36,744	$36,744
	Technical [a]									
11	LCOE (c/kWh)	26.5	25	21.5	19.5	17.5	16	14	12	12
12	Overall annual efficiency (%)	13	14	15	16	17	17.5	18	18.5	18.5
13	% Reduction in CapEx	0	0	10	15	20	25	32	40	40
14	% Increase in capacity factor	0	0	10	15	20	23	26	30	30
15	O&M costs ($/kW-y)	80	80	75	70	65	60	55	50	50
	[a] The overarching economic modelling is required to produce these KPIs									

ASTRI Partners

CSIRO

Australian National University

Flinders University

QUT

University of South Australia

The University of Queensland Australia

The University of Adelaide

Arizona State University

NREL National Renewable Energy Laboratory

Sandia National Laboratories

Australian Government
Australian Renewable Energy Agency

University Partners

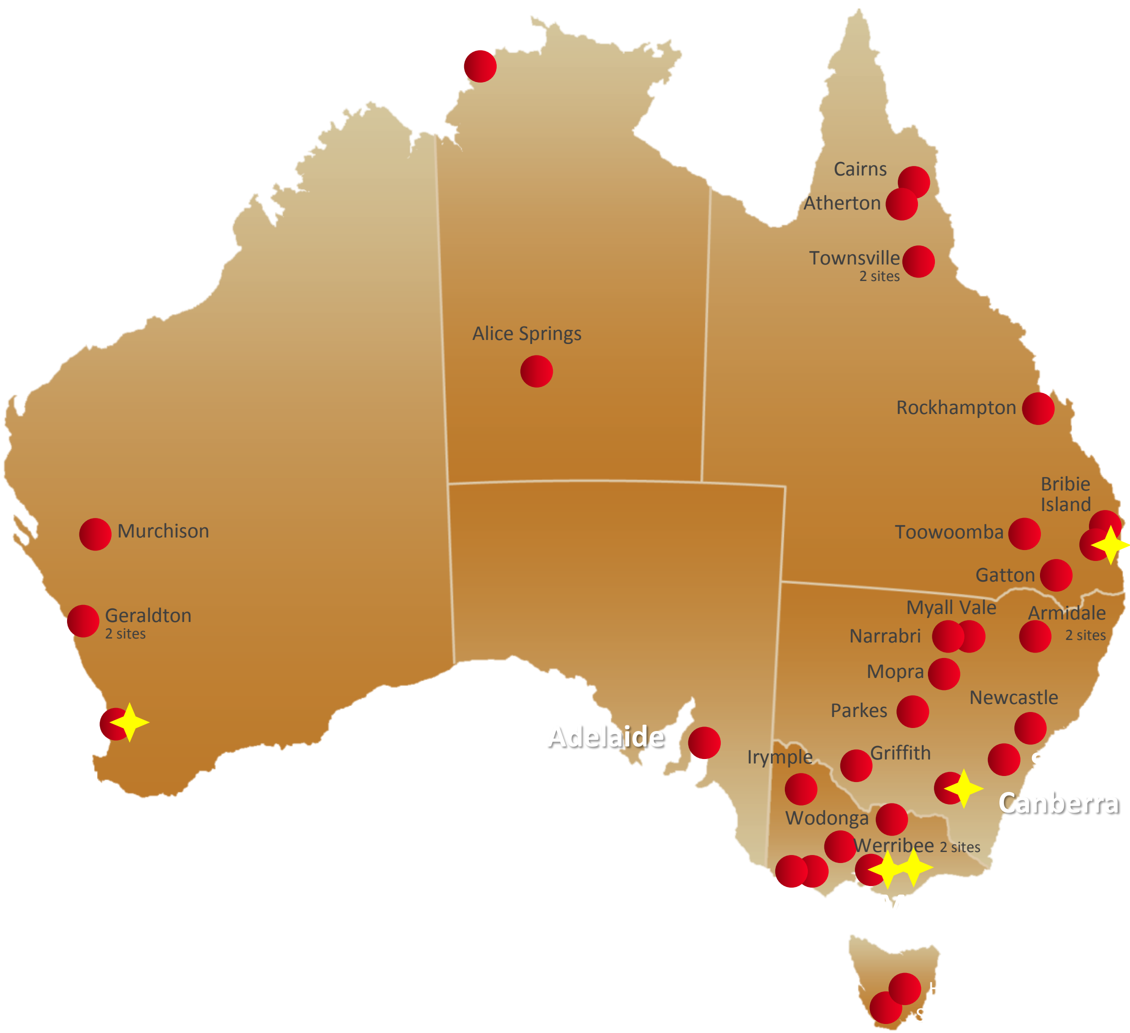
University	World Rank 2014	University	World Rank 2014
The University Of Queensland	47	QUT	352
Australian National University	72	University of South Australia	479
Arizona State University	143	Flinders University	--
The University of Adelaide	191	Source: www.usnews.com/education/best-global-universities	

CSIRO

People	~6000
Sites	55
Flagships	9
Budget	$1B+

64% of our people hold university degrees over **2000** hold doctorates over **500** hold masters

We develop **832** postgraduate research students with our university partners



CSIRO

BR PETROBRAS
Vestas
ABENGOA SOLAR
Deltares
Enabling Delta Life
Australian Government
bp
USDA
RioTinto
Lonza
NOAA
Idemitsu Kosan
中国华能集团公司
CHINA HUANENG GROUP
NASA
中國科學院
CHINESE ACADEMY OF SCIENCES
BOEING
Chevron
Limagrain
Céréales Ingrédients
Universidad de Chile
LOCKHEED MARTIN
BAYER
Fraunhofer
PETRONAS
KIGAM Korea Institute of Geoscience and Mineral Resources
AIST
Queensland Government
NUCTECH
nuseed
CSD COTTON SEED DISTRIBUTORS
woodside
bhpbilliton
ORICA
SANOFI

Human capacity

Institution	Number of People as of 29/10/2014				Total
	Senior Researcher	Post-Doc	Doctoral Student	Other	
CSIRO	7	3	1	0	11
Australian National University	6	1	2	0	9
University of Queensland	10	3	5		18
University of Adelaide	9	3	5	0	17
University of South Australia	6	0	2	0	8
Queensland University of Technology	6	1	4	1	12
Flinders University	4	1	0	0	5
TOTAL	48	12	19	1	80

ASTRI Infrastructure

- CSIRO – National Solar Energy Centre (NSEC)

Infrastructure

- 2 solar towers and field, demonstrated sustained operation above 750°C (500 kWth and 1000 kWth)

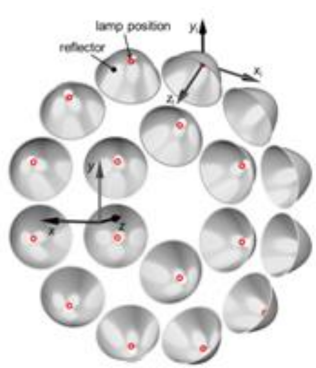
Experimental Capabilities

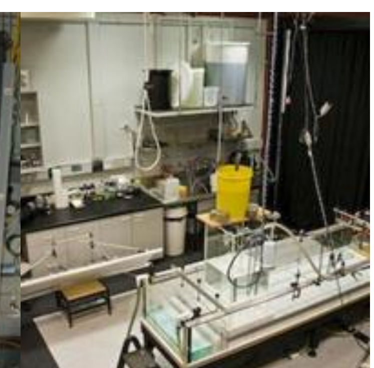
- Computer-based modelling skills that cover a full spectrum of applications from detailed reaction models to process simulation, computational fluid dynamics and transient system performance predictions.
- Laboratory facilities for evaluating the thermal aspects of receiver design
- Laboratory facilities for preparing and assessing novel catalyst development
- Engineering facilities for mirror fabrication and testing

ASTRI Infrastructure

- ANU –Solar Thermal Engineering Group
  - **Infrastructure**
    - Solar concentrators: 3.5-m^2 solar trough, 20-m^2 dish, 400-m^2 dish, 500-m^2 dish
    - 45-kW_e high-flux solar simulator (in preparation)
    - Solar heating and cooling
    - Fundamental research: optics, radiative spectroscopy and radiometry, thermochemistry, materials characterization
    - Also facilities for optics, thermochemistry, fluid mechanics, heat transfer, materials characterization





ASTRI Infrastructure

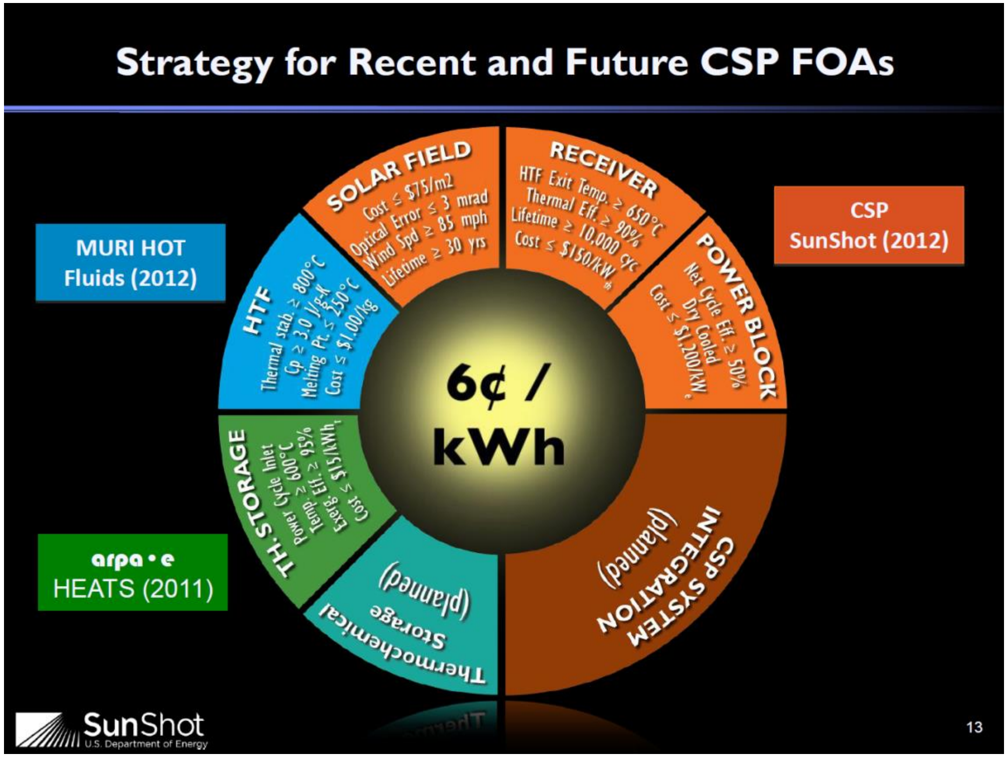
UQ - Turbine test facility

QUT - Dust-Monitoring equipment

UQ – Gatton wind tunnel

USA Solar Energy Collaboration

- The ASTRI objectives link into the SunShot objectives through collaboration with:
  - initially
    - Sandia National Labs
    - NREL
    - Arizona State University
  - Other
    - US labs
    - Universities, and
    - Industry



Source: US DOE (2012) presented at USASEC workshop 8-Jun-2012, Austin, Texas

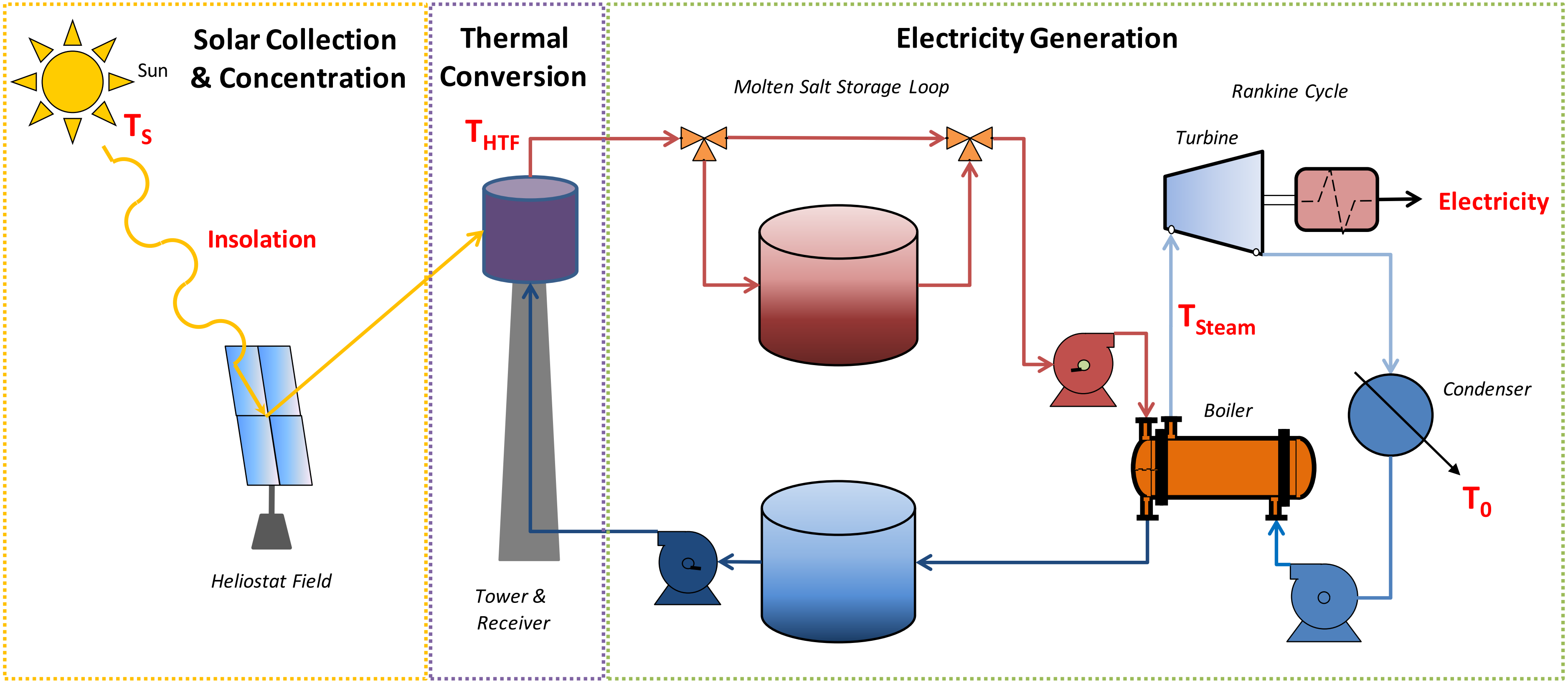
ASTRI Research Nodes and Interactions

	Nodes and Project Collaboration		CSIRO	ANU	UQ	UoA	UniSA	QUT	Flinders
P01	**Overarching Economic Model**	1	Lead		x	x	x	x	x
	Node 1: Reduce capital expenditure (CapEX)			Lead					Sub Lead
P11	Heliostat cost reduction	2	x	Lead		x	x		x
P12	Receiver performance	3	x	Lead	x				x
	Node 2: Increase capacity factor		Lead				Sub Lead		
P21	Storage thermo-economic model	4	*Lead*	x		x	x		
P22	Reliable low-cost PCM storage	5	x				Lead	x	
	Node 3: Improve efficiency		Sub Lead		Lead				
P31	Supercritical CO2 system development	6	Lead		x	x			
P31A	Supercritical CO2 power block		x		Lead			x	
P31B	Supercritical CO2 system		*Lead*		x				
	Node 4: Add Product Value					Lead		Sub Lead	
P41	Cleanliness and cleaning	7	x		x			Lead	
P42	Solar reactor development	8	x	x		Lead			
P02	**Education Program**	9		x	x	Lead	x	x	x

Education Program

- Objective:
  - Develop CSP technical courses and enhance research opportunities for higher degree research (HDR) students in CSP
- Approach:
  - Develop modules for undergraduates, master’s and intensive courses
  - Use e-learning tools
  - Invited lectures from world experts
  - Develop and share practicals to improve experience

We are working on…



- Heliostats
- Heliostat field configurations

- Receivers
  - Liquid metals
  - Particles

- Thermal Storage
  - PCM
  - Thermo-chemical
  - Others

- Power block
  - sCO2
  - Others

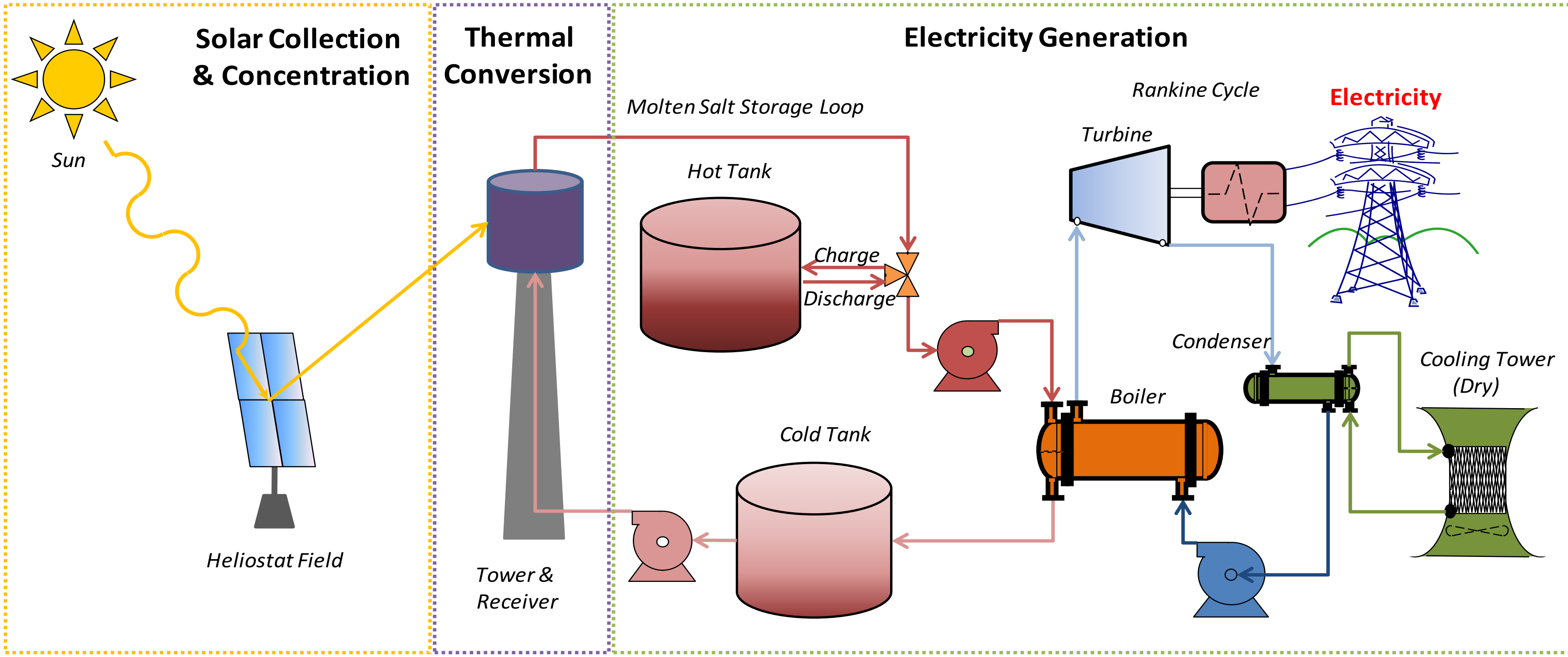
P01 OEM

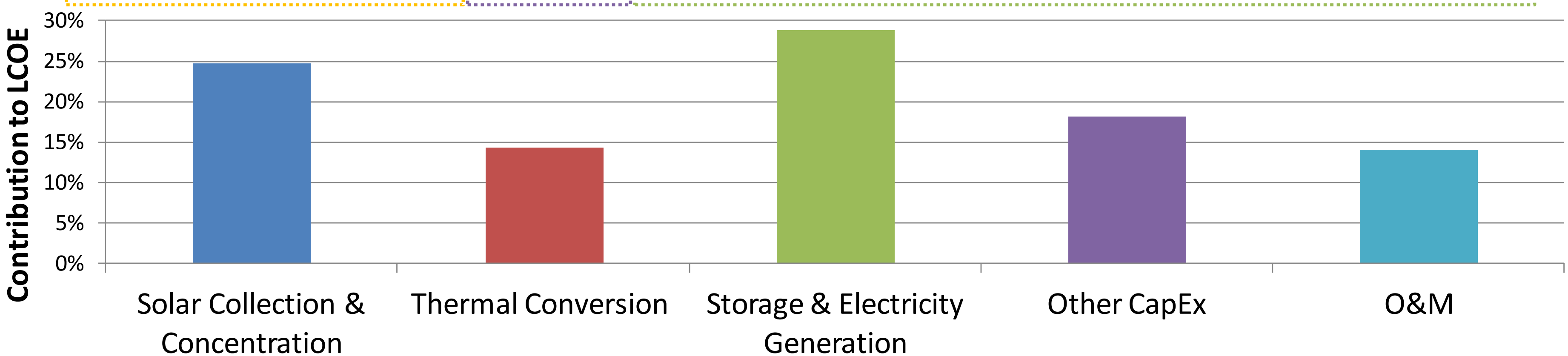
The Overarching Economic Model project has a primary objective to develop a model framework for evaluating ASTRI progress against the Technical KPIs.

This is aided through several contributing objectives:

- Development of cost models for current commercially available CST plant components
- Collaborative development of cost and performance models for new ASTRI technologies
- Expansion of the solar data sets for more rigorous analysis of technology performance under real conditions
- Analysis of uncertainty and sensitivity in CST systems to assist in establishing the best ASTRI research targets.

Central Receiver Tower Reference Case

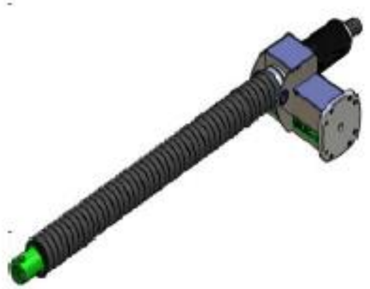




P11 Heliostat Field Cost Down

- Demonstrate proof-of-concept for a new, low cost heliostat
- Technical KPI is $\$120/m^2$ inc. manufacturing, installation, commissioning
- Stretch target is $\$90/m^2$ … and this is the figure we are aiming for!
- High level of collaboration (actively involves all but one ASTRI party)
- Product focus targets partnering and engaging with industry, encouraging commercialisation
- Execution by emerging and mid-career researchers, good vehicle for building human capacity in solar R&D
- Carry out some top quality R&D!

P11 Heliostat Field Cost Down



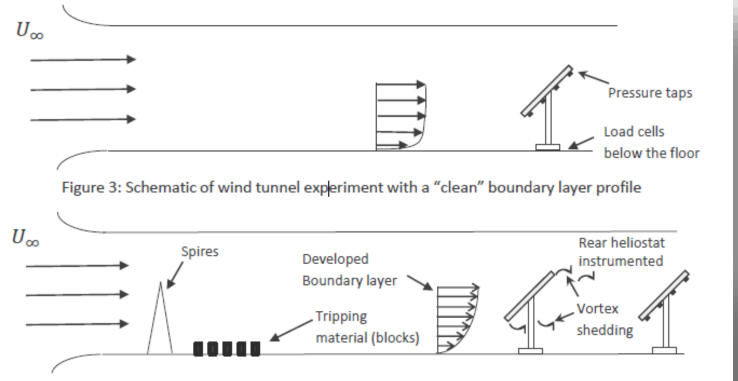
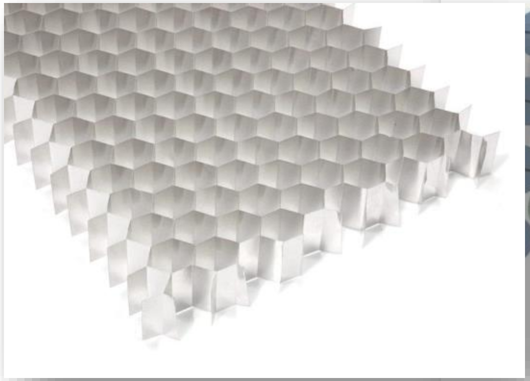
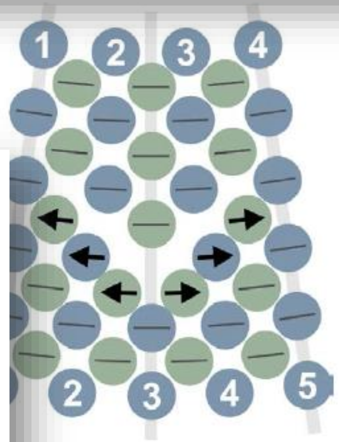
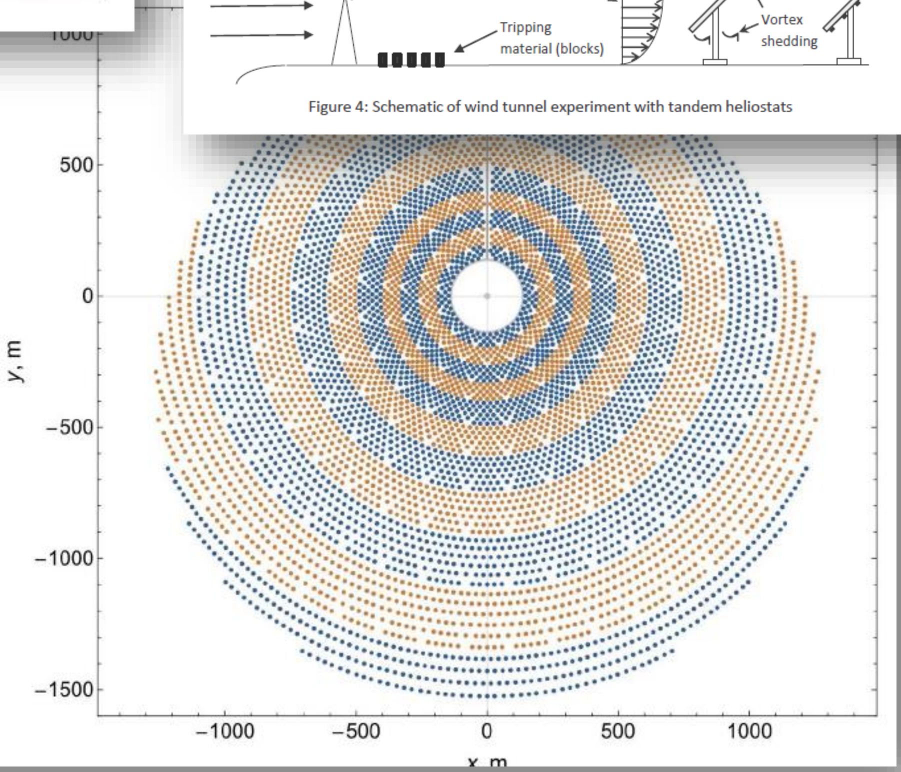


Figure 3: Schematic of wind tunnel experiment with a "clean" boundary layer profile

Figure 4: Schematic of wind tunnel experiment with tandem heliostats



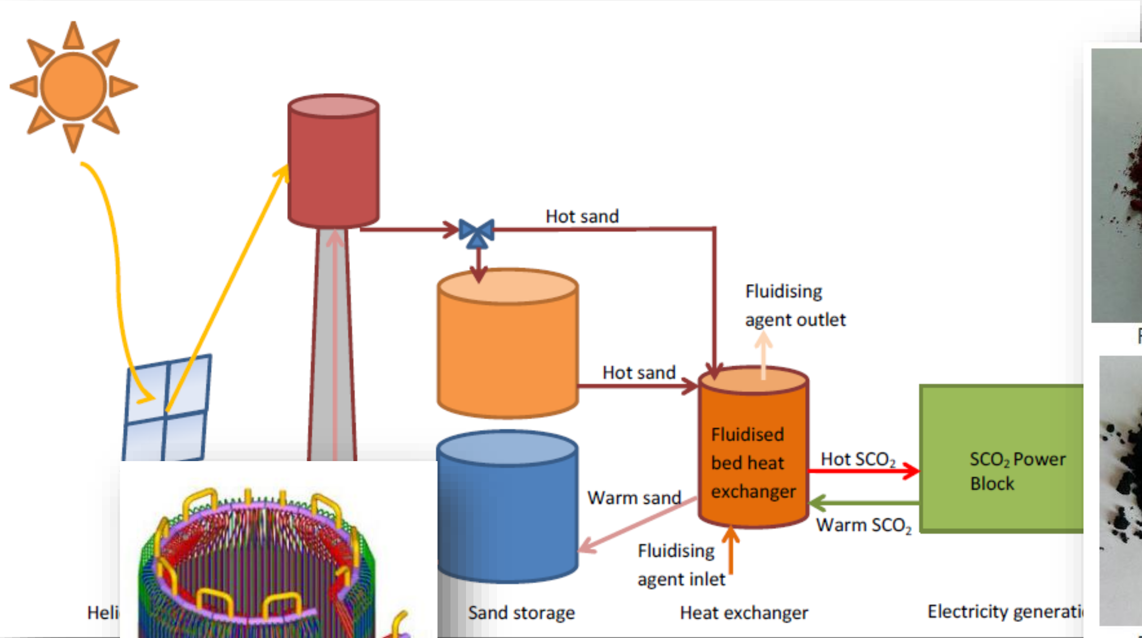


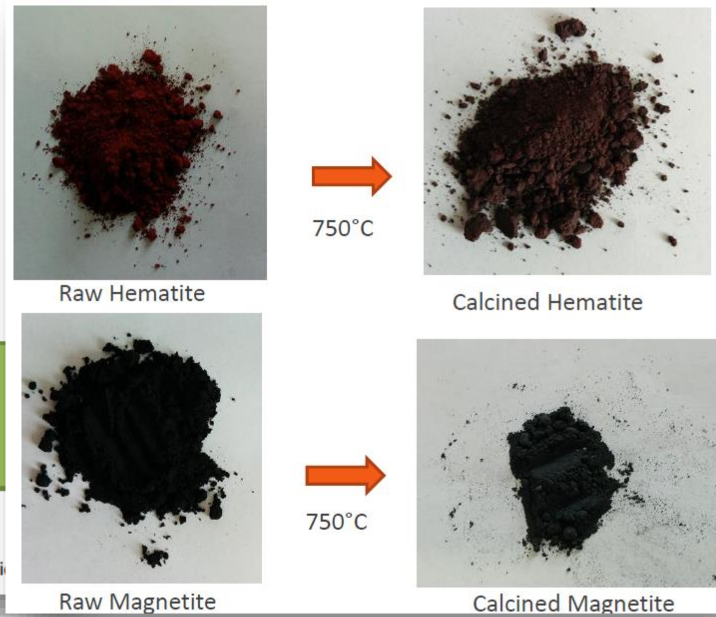


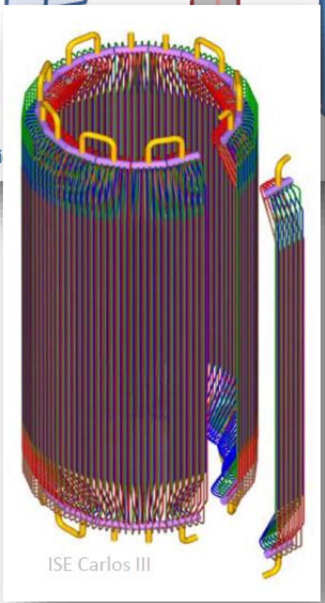
P12 Receiver Performance

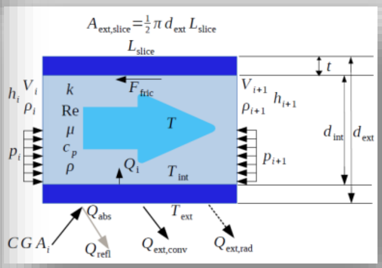
- Demonstrate proof-of-concept for two promising high-efficiency receiver concepts: a tubular receiver and a particle receiver.
- Technical KPIs:
  - Tubular receiver: 91% thermal efficiency at design point (i.e. outgoing fluid at 700°C with 1 MW/m^2 average flux)
  - Particle receiver: 85% thermal efficiency at design point (i.e. outgoing particles at 800°C with 1 MW/m^2 average flux)
- High level of collaboration, linkages to other work within ASTRI (storage, sCO2 Brayton)

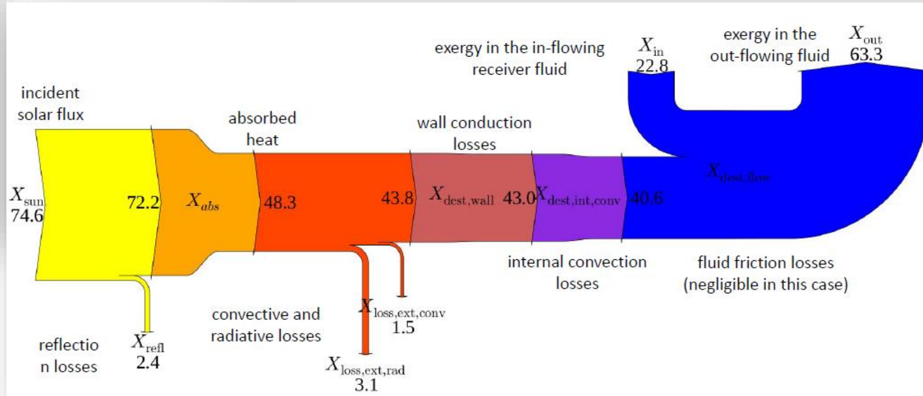
P12 Receiver Performance











P21 High temperature storage

- *Identify and* ***develop storage technology*** *that affords a 20 percentage point increase in capacity factor above the trough reference case without increasing LCOE.*

This will be achieved by:

- Developing a **common-basis modelling platform** to support annual performance and techno-economic analysis of a range of candidate storage technologies, including optimisation of design and operational strategy. This will be a new tool, providing high-fidelity assessment and optimisation of different storage concepts and their associated operational strategies. It will also provide direction to the experimental direction.

- Undertaking targeted **experimental evaluation** of materials and heat transfer processes to support system-level storage concept development, to improve the accuracy of performance estimation for novel storage systems and materials and improve understanding of limiting design factors and materials constraints.

P21 High temperature storage

Systems	Storage Density: Heat of Reaction (kJ/mol)	Storage Density: Specific Energy Storage (kJ/kg)	Storage Density: Heat Reaction (kWh_t/m^3) (STP)	Increment/Decrease on storage density
Carbonates/Hydroxides				
Ca(OH)2/CaO	100	1350	300	1.43
CaCO3/CaO	167	1670	1253	5.96
SrCO3/SrO	234	1585	1647	7.84
BaCO3/BaO	305	1546	1840	8.76
La2O2CO3/La2O3	145.5	393	284	1.35
Gas Cycles*				
Ammonia	67			
Steam Reforming of Methane	205			
Dry Reforming of Methane	247			
Sulfur Based TES (sulfur combustion)	300			
H2S Thermolysis	90.5			
Methanolation-Demethanolation	90.7			
Chemical Looping Combustion*				
ZnO/Zn (CL)	450			
SnO2/SnO (CL)	557			
Fe2O3/FeO (CL)	58.1			
NiO/Ni (CL)	934			
CuO/Cu (CL)	545			
Redox Metal Oxides				
Co3O4/CoO	202.			
Mn2O3/Mn3O4	31.9			
BaO2/BaO	77			
CuO/Cu2O	64.5			
La2CoO4/La2CoO4+δ	485 - 3			
Molten salts 60%$NaNO_3$ 40%KNO_3	1.53 (kJ•k			

Systems	Abundance and cost of feedstock: Reserves Worldwide (metric tonnes or Earth's Crust)	Price USD per tone/m^3	Cost of feedstock ($/$kWh_t$)
Carbonates/Hydroxides			
Ca(OH)2/CaO	Ca 5% Earth's Crust	400-750	0.19
CaCO3/CaO	Ca 5% Earth's Crust	40-70	0.15
SrCO3/SrO	Sr 370 ppm Earth Crust	280-530	1.20
BaCO3/BaO	Ba 0.03% Earth Crust	200-500	1.16
Gas Cycles			
Ammonia	1.31E+08 metric tonnes	704	0.65
Steam Reforming of Methane	3E+14 metric tonnes	Including Catalyst NiO 1:0.1	0.63
Dry Reforming of Methane	3E+14 metric tonnes	160/tn (CO2)	0.67
Sulfur Based TES (sulfur combustion)	1.80E+08 metric tonnes	200-300 (H2SO4)	0.09
H2S Thermolysis	Synthetic	20000-30000	39.42
Methanolation-demethanolation	Synthetic	[illegible]	[illegible]
Chemical Looping Combustion			
ZnO/Zn (CL)	79 ppm Earth's Crust		
SnO2/SnO (CL)	2.2 ppm Earth's Crust		
Fe2O3/FeO (CL)	63000 ppm Earth's Crust		
NiO/Ni (CL)	90 ppm Earth's Crust		
CuO/Cu (CL)	68 ppm Earth's Crust		
Redox Metal Oxides			
Co3O4/CoO	75 ppm Earth's Crust		
Mn2O3/Mn3O4	680 ppm Earth's Crust		
BaO2/BaO	Ba 0.03% Earth's Crust		
CuO/Cu2O	68 ppm Earth's Crust		
La2CoO4/La2CoO4+δ	Synthetic		
Molten salts 60%Na 40%K	Na 2.6 % Earth's crust		

Systems	Temperatures & Pressures: Charge (^oC)	Discharge (^oC)	ΔTmax	Pressure Charge (kPa)	Pressure Discharge (kPa)	Power Cycle
Carbonates/Hydroxides						
Ca(OH)2/CaO	507	507	0*	101.325	101.325	Out of limits
CaCO3/CaO	880	860	20	101.325	101.325	SC Brayton
SrCO3/SrO	800	800	0*	101.325	101.325	SC Brayton
BaCO3/BaO	1342	1342	0*	101.325	101.325	Out of limits
Gas Cycles						
Ammonia	800	450	0	900-15000	1000-30000	Out of limits**
Steam Reforming of Methane	950	530	420	10000-15000	10000-15000	Out of limits
Dry Reforming of Methane	950	530	420	10000-15000	10000-15000	Out of limits
Sulfur Based TES (sulfur combustion)	850*	1200	920	101.325	101.325	Out of limits
H2S Thermolysis	1097	800	297	15000	15000	SC Brayton
Methanolation-demethanolation	250	200	50	101.325	5000-10000	Out of limits
Chemical Looping Combustion						
ZnO/Zn (CL)	977	500	477	101.325	101.325	Out of limits
SnO2/SnO (CL)	977	500	477	101.325	101.325	Out of limits
Fe2O3/FeO (CL)	825	625	200	101.325	101.325	WS Rankine
NiO/Ni (CL)	1195	717	478	1519.875	1519.875	WS Rankine
CuO/Cu (CL)	900	800	100	101.325	101.325	SC Brayton
Redox Metal Oxides						
Co3O4/CoO	900	870	30	101.325	101.325	SC Brayton
Mn2O3/Mn3O4	980	550	430	101.325	101.325	WS Rankine
BaO2/BaO	780	690	90	101.325	101.325	WS Rankine
CuO/Cu2O	1100	900	200	101.325	101.325	SC Brayton
La2CoO4/La2CoO4+δ	1100	700	400	101.325	101.325	WS Rankine
Molten salts 60%Na 40%K	650	600	50	4053	4053	Rankine

P22 PCM storage

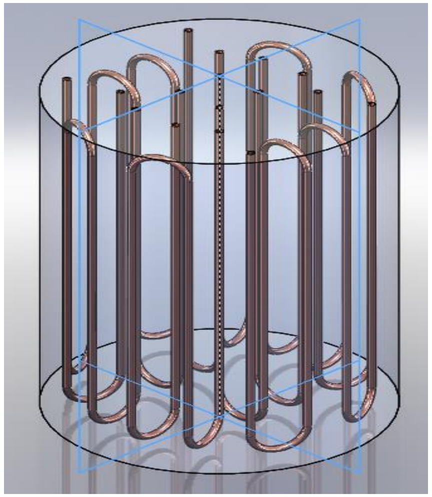
Develop technology for construction of a high performing thermal storage system using PCM, costing less than $25/kWh$_{th}$

- New methods to measure thermophysical properties of high temperature PCMs
- New PCMs with lower cost and better thermophysical properties will be investigated
- Investigate potential materials for construction of the storage tanks
- Cost analysis will be conducted to determine the effect of thermal storage on the LCOE
- Investigate encapsulated high temperature PCM
- Extensive simulations using computer models to evaluate the thermal performance of various storage systems. Different construction materials, thermal storage media and heat transfer fluids (including sCO_2) will be investigated
- Two prototypes will be built and tested for sCO2 CSP application

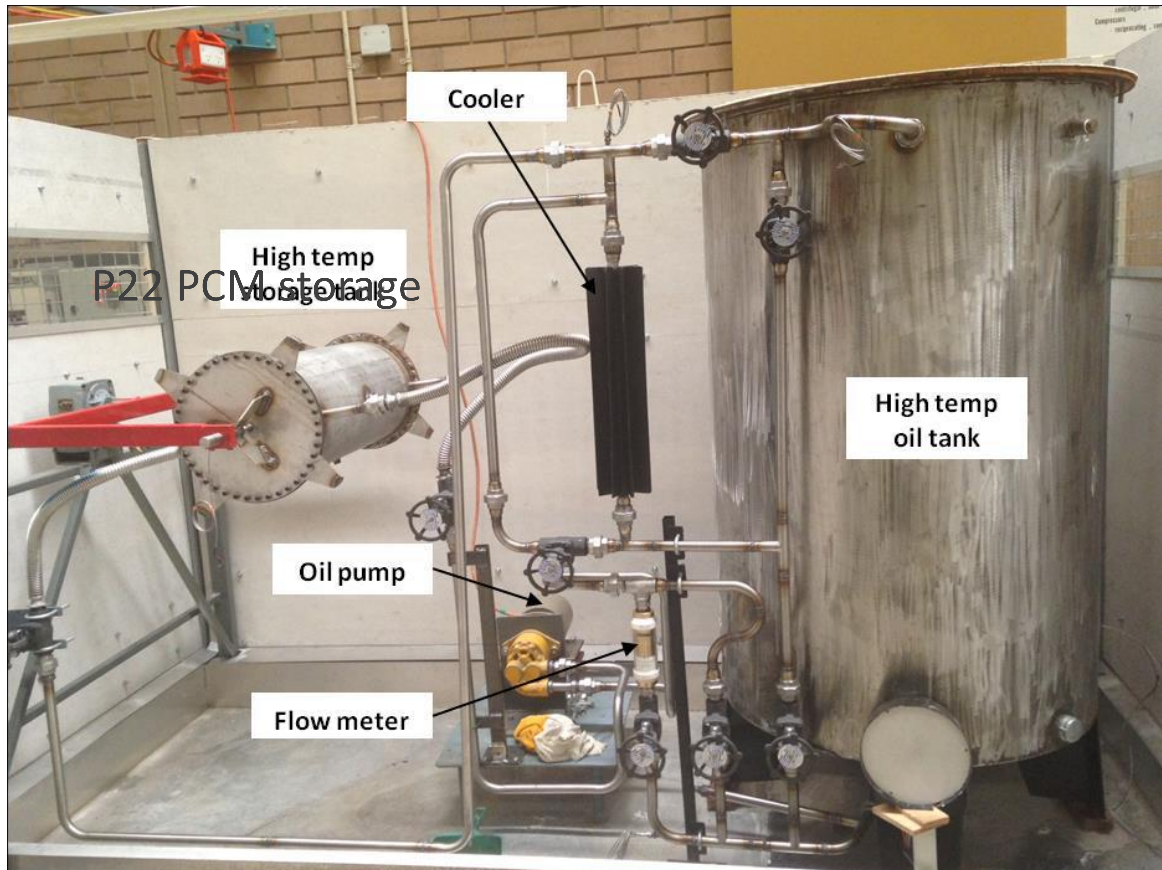
P22 PCM storage

- Technical achievements
  - Literature review of material properties and systems (300 to 710 C)
  - Tested (cycling and stability) potential candidates from 400-650 degrees C
  - Some PCM properties measured do not match those published in the literature
  - Conventional temperature-history method to measure latent energy not valid at high temperatures
  - Techno-economic analysis revealed that some alloys as well as salts should be considered as PCMs

P22 PCM storage - Hot oil test rig

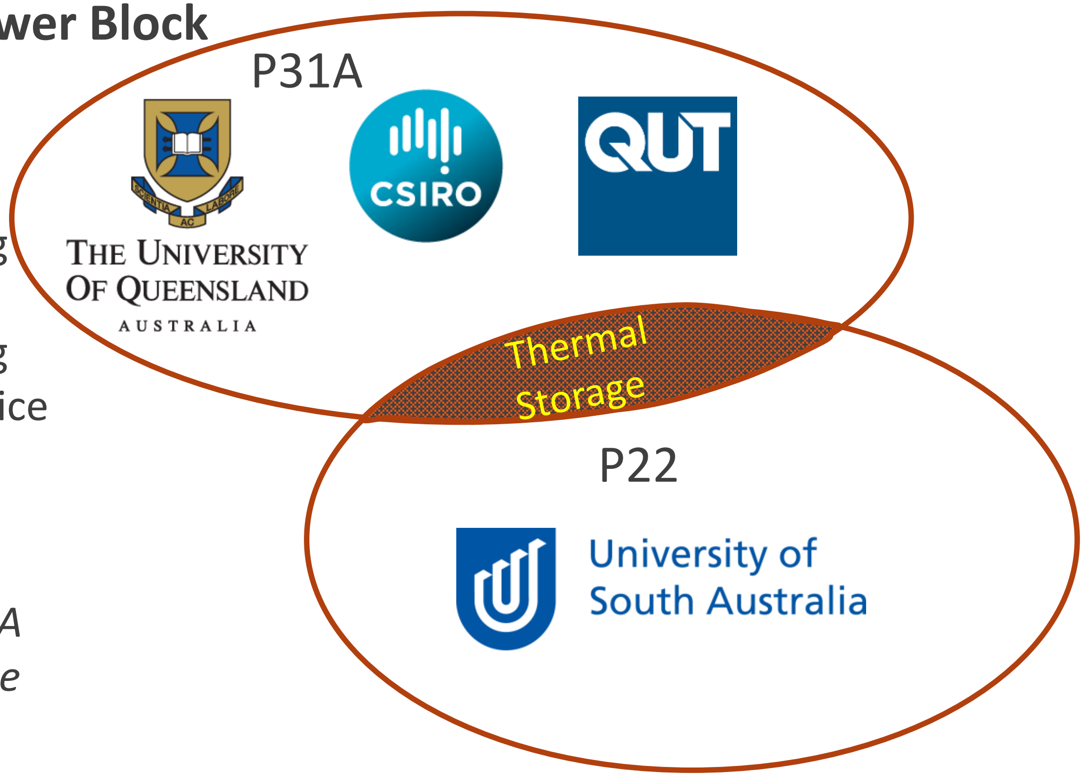


- preliminary validation of computer models at mid-temperature range
- determine potential problems for higher temperature prototypes before construction

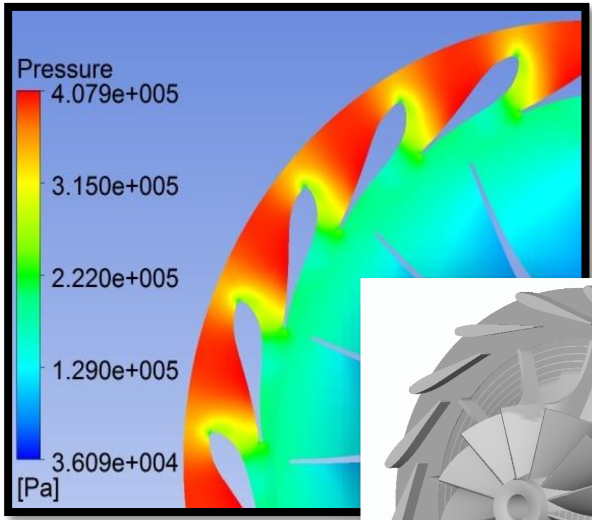


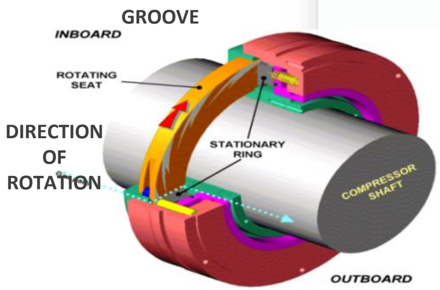
Node 3

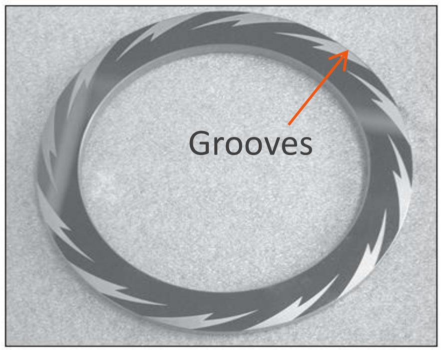
- **P31A - Supercritical CO_2 Power Block**
  - UQ
    - Power Block
    - Hybrid Cooling
    - Techno-economic modelling
  - CSIRO
    - Techno-economic modelling
    - Solar field and Receiver advice
  - QUT
    - Power Block
  - *UniSA*
    - *Not a formal partner in P31A*
    - *Will develop thermal storage*
  - US Partners
    - NREL – Hybrid Cooling Towers
    - University of Texas, Austin, turbo-generator
- **P32 – Alternative Power Blocks**
  - CSIRO
  - QUT

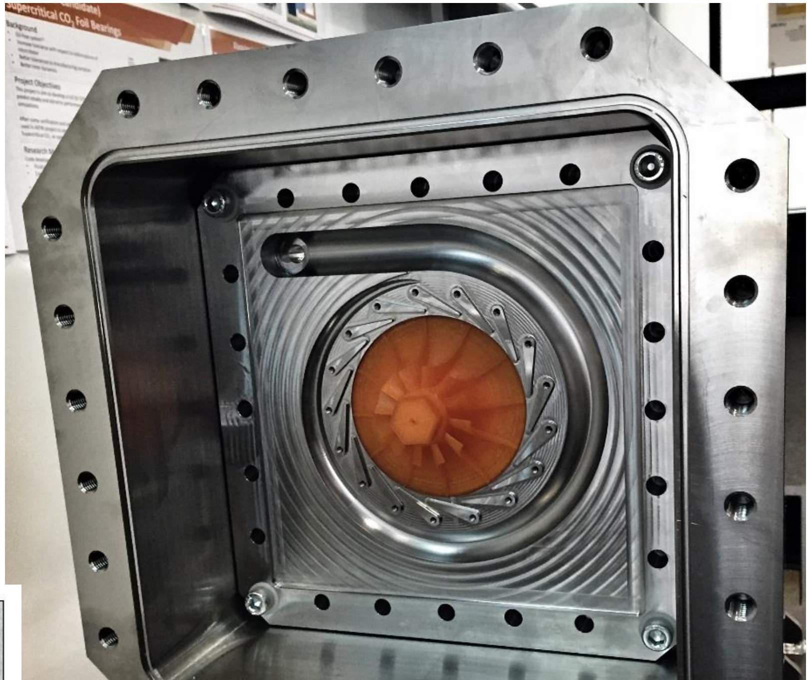


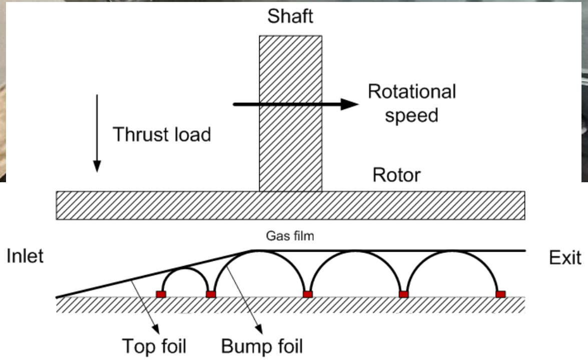
Node 3


Pressure
4.079e+005
3.150e+005
2.220e+005
1.290e+005
3.609e+004
[Pa]

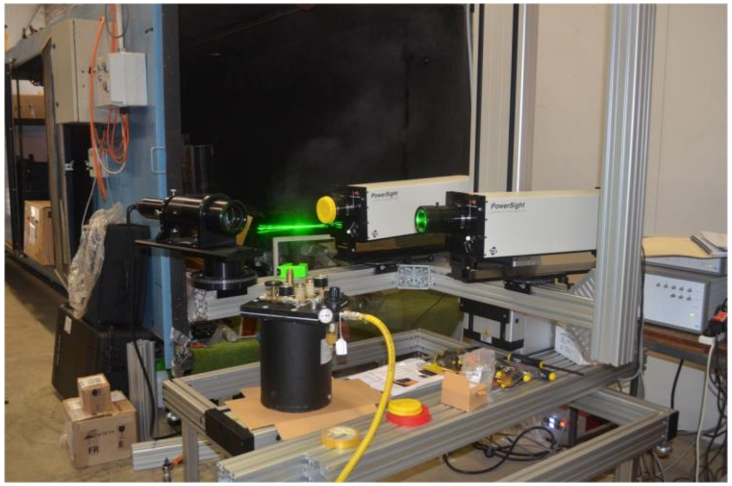

GROOVE
INBOARD
ROTATING SEAT
DIRECTION OF ROTATION
STATIONARY RING
COMPRESSOR SHAFT
OUTBOARD


Grooves

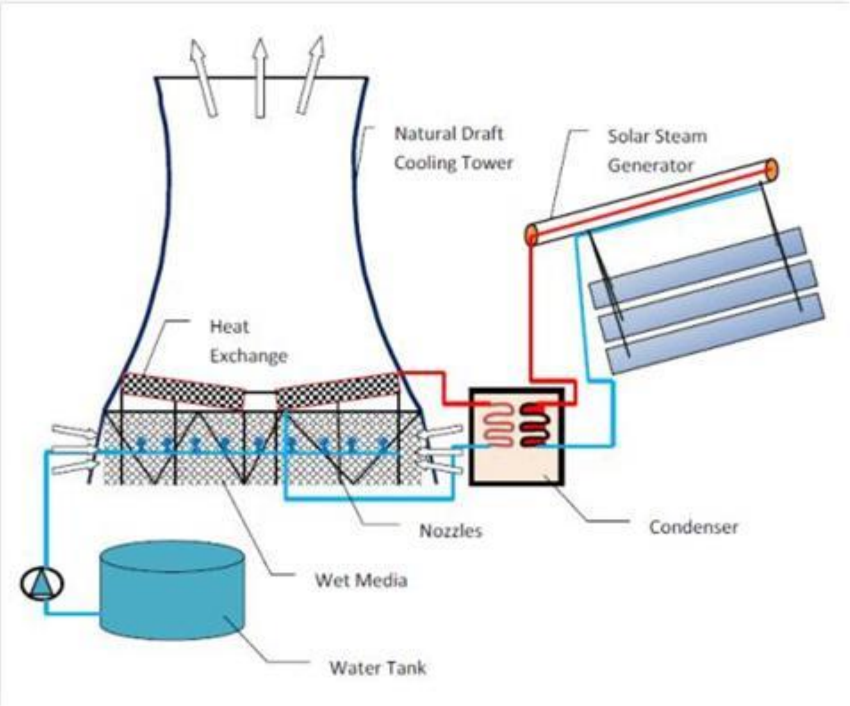



Shaft
Rotational speed
Thrust load
Rotor
Gas film
Inlet
Exit
Top foil
Bump foil

Cooling tower research facilities



- Gatton wind tunnel
- Phase Doppler Particle Analyser (PDPA)
- 20m Tower



Cost Effective O&M - Project Aim

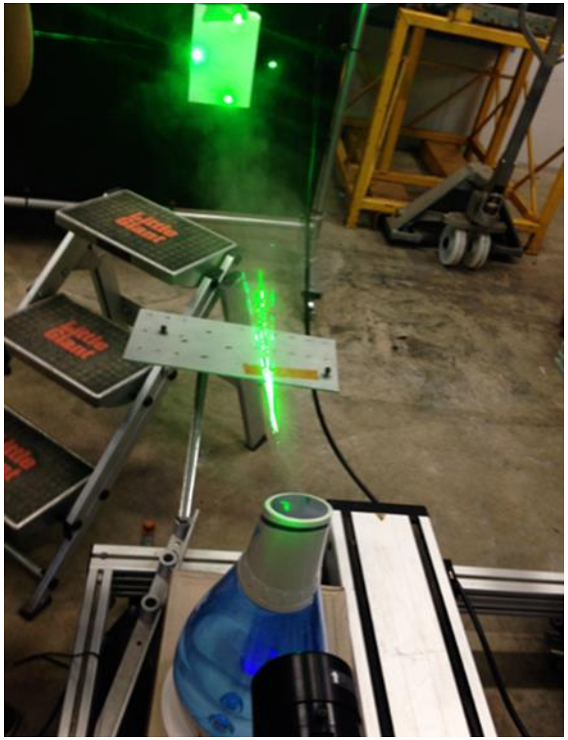
The overall aim of the project is to reduce the O&M component of LCOE from $80/kW-y to $50/kW-y by improving mirror-cleaning efficiency and by optimising O&M tasks.

1) **Mirror cleaning**, which is aimed at reducing cost of cleaning using a non-contact method. The object of the study is to understand the dynamics of spray formation and to quantify effectiveness of cleaning.

2) **Operation and maintenance**. To establish reliability modelling and condition monitoring systems and to make O&M decisions more cost effective and to reduce unexpected failures.

Spray-cleaning Testing Facility

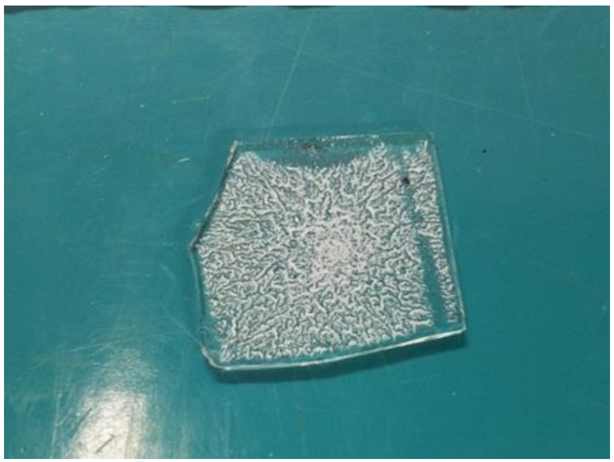
Set-up of spray nozzles.

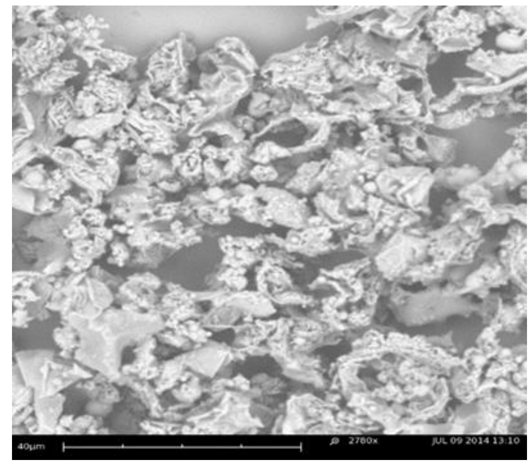


Set-up and alignment of laser for measurement of droplet size and velocity

Self cleaning mirror coatings

Research at Flinders University is aimed at developing silica nanoparticle self-cleaning coatings for mirror surfaces





Early synthesis.

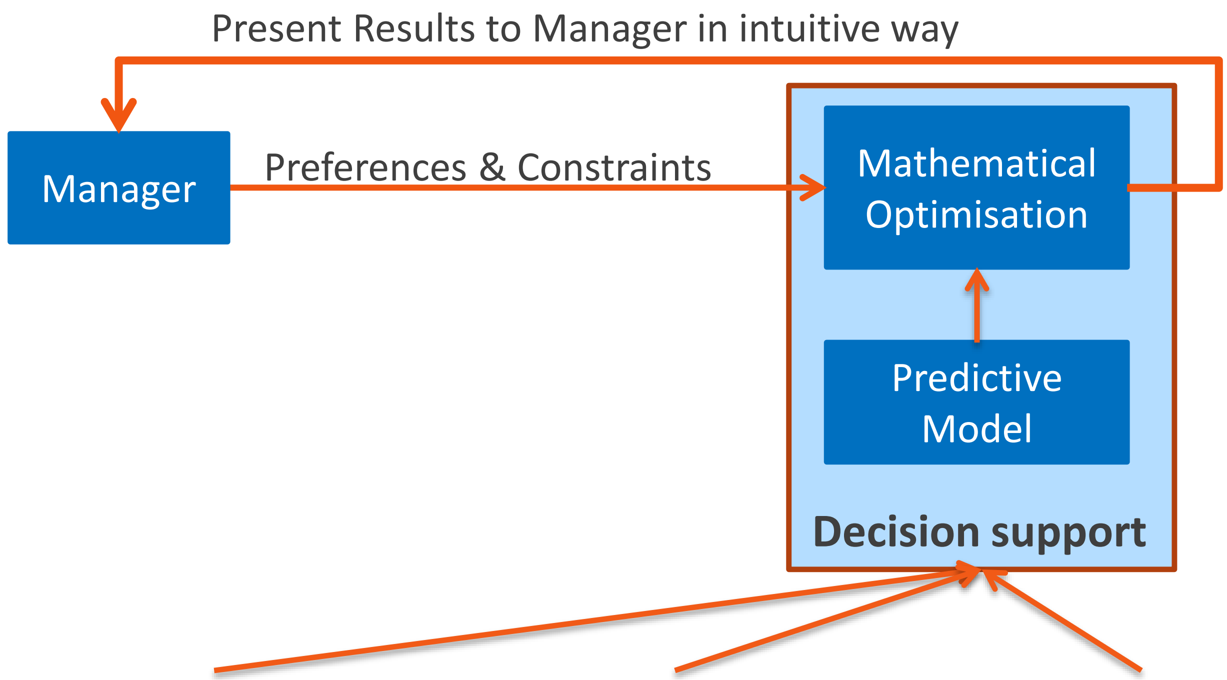
Two types of silica nanoparticles, one with vinyl functionalization and the other with thiol functionalization on the surface. Have managed to get the size to just over 100 nm for both types of particles.

However this film is not transparent and from the SEM appears to have substantial agglomeration.

Decision Support for O&M

Constraints

- **Budget**
- **Staff**
- **Equipment**
- **Market**
- **Weather**
- **Inventory**



SCHEDULED MAINTENANCE

- Staff responsibilities
- Maintenance times
- …

CONDITION MONITORING

- Vibration analysis
- Thermography
- …

HISTORICAL FAILURE DATA

- Work orders
- Plant stops
- …

Getting Involved

- **Industry partnerships**
- ASTRI is keen to develop mutually beneficial relationships with industry in
  - Individual projects related to the various processes involved in a CST plant
  - A range of projects with a systems concept

- **Current student positions**
  - At ANU - Solar fuel production via supercritical water gasification of biomass
  - At ANU - Concentrating solar thermal optical modelling
  - At ANU – Sensible energy storage coupled to a sodium receiver

http://www.astri.org.au/get-involved/

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University of South Australia

QUT

Flinders UNIVERSITY

Thank you

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