AUSTRALIAN SOLAR THERMAL RESEARCH INITIATIVE

ASTRI Annual Report

Australian Solar Thermal Research Initiative

December 2012 – October 2013

WWW.ASTRI.ORG.AU

ARENA Program Information

INFORMATION FIELD	CONTENT
Grantee Name	Commonwealth Scientific and Industrial Research Organisation
Collaborating Organisations	Australian National University The University of Queensland The University of Adelaide University of South Australia Queensland University of Technology Flinders University
International Collaborating Organisations	National Renewable Energy Laboratory (NREL) Sandia National Laboratories (SNL) Arizona State University (ASU)
Subcontractors	nil to date
Program Title	Australian Solar Thermal Research Initiative (ASTRI)
Program Number	1-SRI002 (ASTRI)
Annual Report Period	1-Dec-2012 to 31-Oct-2013

ASTRI at a Glance

ASTRI – Australian Solar Thermal Research Initiative

ASTRI is a consortium of leading Australian research institutions collaborating to deliver cost reductions and dispatchability improvements, as well as position Australia in concentrating solar thermal (CST) power.

Grant Recipient

CSIRO

ARENA Funding

$15 million (years 1-4)

ARENA Funding

$20 million (years 5-8)

Total Project Value

$87.3 million

Challenge

Concentrating solar thermal (CST) technologies concentrating sunlight to create high-temperature heat for power generation, solar chemistry and other industrial processes. With Australia's solar resource, CST technologies have the potential to be an important part of the future energy mix, although innovation is required to make the technologies more cost competitive. Australia has the research expertise to deliver leading-edge solar thermal concepts and profit from the growing CST sector.

Approach and Innovation

ASTRI's innovations will be achieved through a series of highly targeted research projects, in close partnership with United States research collaborators and with leading international and Australian CST companies.

ASTRI will achieve its outcomes through USA Solar Energy Collaboration (USASEC) linkages to the US Department of Energy SunShot program, and through mobilising the international CST industry to invest in Australia.

ASTRI is coordinating a focused program with rigorously prioritised efforts, informed by an overarching economic model.

Together, the collaborating ASTRI organisations will produce a large-scale collaboration on CST across Australia, serving as a platform for new international linkages. It will develop a step-change in the commitment of Australian researchers to the success of CST, as well as equip highly-trained graduates ready to deliver success in CST industries.

Outcomes and Benefits

ASTRI will deliver the next wave of CST cost reductions to deliver solar electricity at 12 cents per kWh and demonstrate the added-value that CST technologies bring to the energy marketplace. In doing so, ASTRI is delivering:

- Relevant research outputs such as novel technologies, know-how, patents
- Concepts ready for commercialisation will be initiated
- Knowledge sharing through media presence, publications and presentations

Researchers will also be equipped to engage in the science and technology debates that will underpin Government policy towards CST adoption.

Contents

Message from the Chair

The renewable energy industry is a vital element of Australia's economy and future prosperity. Australia has the potential to benefit significantly from renewable energy technologies, and for generations to come, if supported by appropriate policy mechanisms.

Australia is uniquely advantaged to benefit from solar energy. We have an advanced, first-world economy, an educated workforce, domestic security and, above all else, as a result of our geography we have an outstanding solar resource. The research and teaching capabilities of our universities, CSIRO and other institutions, is strong.

In combination, it is clear that Australia has all the necessary structural attributes to become a leading light in research, teaching, experimentation, demonstration, deployment and utilisation of solar energy. It is the role of government, at all levels, to develop and maintain an appropriate policy framework to ensure this occurs.

Solar thermal technologies can deliver abundant energy from renewable sources. These technologies have potential in a range of settings in the Australian context, on-grid and off-, adjacent to our cities, and in remote locations. Australia will benefit significantly as the cost of deployment of solar thermal systems continues to fall.

There is a strong case for public investment in research and teaching in a sector in which Australia has natural advantages. ASTRI is an example of sound public policy supporting renewable energy research.

ASTRI represents:

- a great idea – concerted research effort to reduce the cost of solar thermal systems
- in the right environment – Australia
- combining seven excellent research and teaching organisations
- partnering with several of the best solar thermal research laboratories across the world.

The successes of ASTRI in its inaugural year, summarised in this document, are clear. Research teams on all seven campuses have mobilised and work is well underway. New recruits have started and new postgraduate research students have enrolled. The research teams have clear plans and targets, and a clear focus on safety and collaboration and first-rate research. After only one year since its foundation, it is very encouraging to see ASTRI in such a healthy position.

Looking forward, there are many challenges ahead for ASTRI. This is an ambitious research programme and clearly there is a lot of work still to be done. On top of the already large workload, I encourage all members of the ASTRI team to communicate their work broadly and generously, via academic journals and the media. ASTRI, via its size and sector dominance, has a responsibility to lead and educate the community. In the midst of a challenging political debate, where Commonwealth energy policy appears to be in a state of flux, ASTRI has an important role to play in helping our Federal and State Governments understand the potential community benefits of solar power.

Finally, thanks to all of the hardworking women and men of the ASTRI team – supervisors, researchers, students and support staff – your contribution to this initiative is important and highly valued.

Kieran Jacka

Chair, ASTRI Advisory Committee.

Senior Manager, Engineering, ACCIONA Energy Australia

Message from the Director

Among viable renewable energy alternatives, Concentrating Solar Thermal (CST) technologies are unique in their ability to provide both flexible electricity supply to the power grid, as well as energy input for other industrial processes. This creates the opportunity to sustainably manufacture a new generation of energy intensive products.

ASTRI's research goal and strategic intent is to deliver the next wave of CST power cost reductions and dispatchability improvements in Australia by both incremental and disruptive technology improvements. This first year of ASTRI has been a busy productive period for formulating projects and developing new interconnected teams of researchers. In addition, we have been creating and adopting tools to co-ordinate this large-scale collaboration, which are targeted at furthering ASTRI's ambitious goals.

A challenging characteristic of CST systems is that substantial improvements from the current state of the art of the technology are to be expected, not necessarily by a radical improvement or cost reduction in any one component, but through the combined effect of improvements and cost reductions in the many components of a CST plant.

Breakthroughs in solar thermal energy technologies will very likely be achieved by multidisciplinary teams mastering material sciences, chemistry, optics, structural modelling, analysis and design, fluid-mechanics, heat transfer, scientific computing, and mathematical modelling and optimization. Transformative breakthroughs will be made possible by these teams working collaboratively, and whenever needed, with biologists, architects, economists and other professionals. This will enable the exploration of novel ideas such as biologically inspired designs, meta-materials, nano-enhanced surfaces and fluids, or a combination of these ideas.

With its outstanding solar resources and its scientific and industrial capabilities, Australia is well-positioned to play a leading role in the development and deployment of solar technologies worldwide, both thermal and photovoltaic. By accepting this role, we will be doing our share to ensure the sustainability of life on the planet, because that sustainability is dependent on the widespread development of renewable energies, especially solar energy. This is not an abstraction: sustainability should be one of our most important implicit and explicit priorities, if not the most.

To improve our chances to achieve both incremental improvements and transformative breakthroughs through energy research, we must:

- Have a clear plan
- Be disciplined
- Be good at assessing situations
- Consider responsible choices
- Be always vigilant for signs of changes in the physical, financial, social and technological environments
- Adjust when circumstances change.

Through its "Overarching Economic Model", ASTRI has defined a trough baseline and a tower reference which will facilitate and enable quantification of progress as we further ASTRI's goal of cost reduction.

The heliostat and receiver scoping studies aimed at reducing capital expenditure have provided a solid platform for assessing solar field innovations. Thermal storage at high temperatures, which is required to improve the capacity factor of CST plants, may be achieved by phase change materials. Increasing efficiency through the use of new power cycles, such as those using supercritical carbon dioxide, requires system development, beginning with engineering fundamentals of turbine design and condensing technologies. Adding value through the reduction of operation and maintenance, in such tasks as the cleaning of mirrors in dry environments, has important immediate commercial consequences for stationary energy. Creating new products, such as solar fuels, is emerging as a realistic mid-term solution for the challenge posed by the transportation needs of a fast growing and increasingly dynamic population. Last, but most important, ASTRI's education program currently designing and preparing focused modules that will be made available to a motivated population. This program will provide the necessary insights and skills to educate and train the future workforce that is essential for a vibrant Australian CST industry.

I have participated in a large number of national and international expert groups and committees and represented Spain in various international scientific forums. I have played a leading role in most major CST technology research and development and demonstration projects undertaken in Europe in the last 25 years. I bring to my work with ASTRI the outlook and the experience of many years working with a wide variety of talented scientists, engineers, educators and administrators. While ASTRI was born as a collaborative effort between Australia and the United States of America, its goals are shared by many talented professionals elsewhere, and it is right, if not imperative, to broaden now the extent of the original collaboration.

During my new tenure as the Chairperson of the International Energy Agency's SolarPACES Implementing Agreement, I will do my best to contribute to the alignment of worldwide research efforts to increase the cost-competiveness of CST power and solar chemistry technologies. I am honoured and proud to lead ASTRI and to help maintain the conditions that make its complex and ambitious work an excellent example of collaboration, where talented and hard-working professionals join effort to make CST an improved energy option and allow it to develop its rich potential.

Dr Manuel Blanco Ph.D., Dr.Ing.

Director, ASTRI and CSIRO Solar Thermal Group Leader

Highlights and Achievements

The first year of ASTRI has been devoted to **developing a portfolio of well-defined research** project proposals to meet the ASTRI objectives and key performance indicators (KPIs) involving meaningful collaboration.

Technical developments

Heliostat and receiver scoping studies reviewed cost and technical performance for concentrating and capturing solar radiation, paving the way to develop targeted projects.

Initial assessment predicts a supercritical CO_2 power block will significantly reduce LCOE. Realising this will depend on meeting the cost and technical assumptions.

ASTRI is growing with quality staff, postdoctoral fellows and students.

⇒ Dr Manuel Blanco commenced as ASTRI Director in January 2013 and re-appointed as the Chairman of SolarPACES in September 2013

Professor Wojciech Lipinski commenced as ANU's new leader in Solar Thermal Engineering 2013 and an ASTRI Principal Investigator

An example of early **stakeholder engagement** is an award to The University of Queensland for hybrid cooling research infrastructure from the Queensland State Government Futures Co-Investment Fund. Within ASTRI, this infrastructure will be used to test CST power block cooling concepts suited to arid regions and expands the scope of the ASTRI project and its outcomes.

Knowledge Sharing

⇒ ASTRI launch with media releases and webpage www.csiro.au/astri

⇒ Media release announcing commencement of Dr Manuel Blanco (Feb-13)

⇒ Advertising of postdoctoral fellowships and PhD scholarships providing some details of the direction of ASTRI's research

⇒ Publications on CST supercritical CO_2 systems fundamental issues (dynamics) and SolarPACES poster papers related to the technical and market opportunities

⇒ Presentations at key Australian and International CST events such as Solar2013 and SolarPACES 2013

Visits related to **US Collaboration** included:

⇒ Prof Ellen Stechel (ASU) attended ASTRI workshop in February 2013

⇒ US research leaders visited Australia and ASTRI for SolarPACES ExCo meeting in April 2013

⇒ ASTRI Director invited to SunShot Concentrating Solar Power Program Review in April 2013

⇒ Mr Wes Stein based in the US in August and September 2013 to develop collaborative relationships

⇒ ANU field trip visit to Sandia National Lab and Crescent Dunes in September 2013

ASTRI Governance

The governance framework within ASTRI has a node structure to ensure the partners commit to the broader strategic objectives. The intent is to produce synergies and collaborative outcomes greater than each partner can independently realise. ASTRI has been implemented through:

- a Funding Agreement between ARENA and CSIRO as the ASTRI lead party, and
- a Collaborative Research Agreement between CSIRO and the Australian Universities to pass through required terms and provide a framework for the conduct and management of the Program.

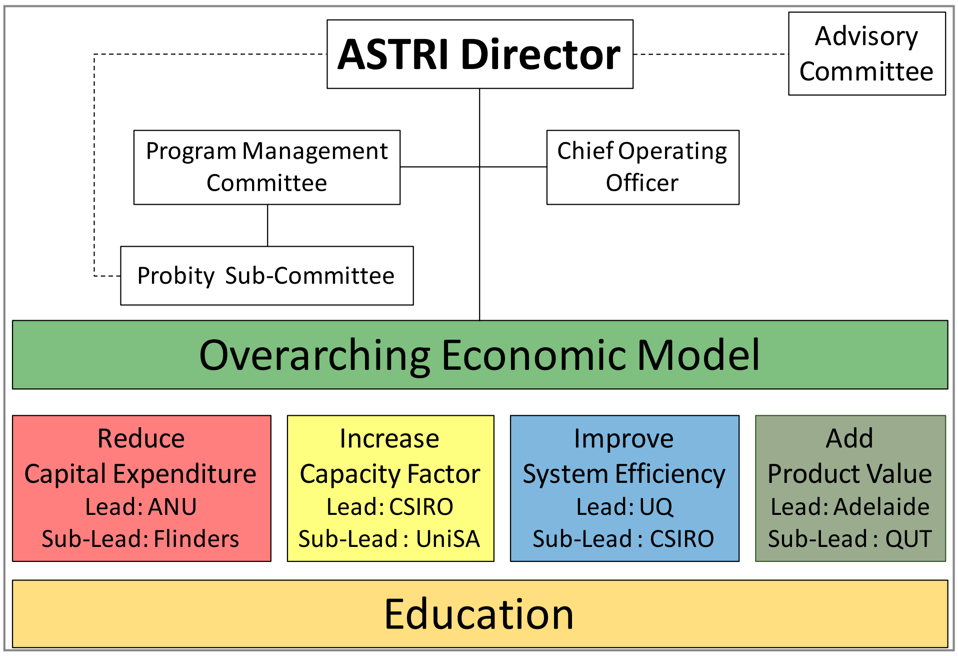
The Australian partner institutes that make up ASTRI are six universities and CSIRO. The universities involved are:

Australian National University (ANU)	University of Queensland (UQ))	University of Adelaide (UA)
University of South Australia (UniSA	Queensland University of Technology (QUT)	University of Flinders (UF)

The three key governing bodies within ASTRI are the Advisory Committee, Program Management Committee, and the Probity Sub-Committee.

- *Advisory Committee:* provide advice on the strategic direction of ASTRI through review and contributions to the development of annual strategic plans. The members of the Advisory Committee have been chosen to include representatives with research management, finance and commercial skills and experience.
- *Program Management Committee:* provide advice and assistance to the ASTRI Director on the research program and ongoing management of ASTRI. The Program Management Committee comprises the Principal Investigators, who represent their university and the node in which their university is a leader or sub-leader.
- *Probity Sub-Committee*: review decisions in ASTRI about CSIRO, since the Director is a CSIRO employee. The membership is from the Program Management Committee to provide support on decisions relating to resources and conflicts of interests and probity.

ASTRI Governance Reporting Structure



Advisory Committee Members

Chairman and Industry Advisor

Mr Kieran Jacka

Acciona

Senior Manager, Engineering

Industry Advisor

Mr Anthony Wiseman

AREVA

Regional Director & General Manager Australia

ARENA Representative

Ms Louise Vickery

Renewable Futures

General Manager, Project Delivery

ARENA Representative

Ms Veronica Heard

Renewable Futures

Team Leader

CSIRO Representative

Dr Jim Smitham

CSIRO Energy Flagship

Deputy Director

Program Management Committee Representative

Prof Paul Meredith

Principal Investigator

University of Queensland

Program Management Committee

Chairman

Dr Manuel Blanco

CSIRO

ASTRI Director

Mr Wes Stein

CSIRO

Principal Investigator

Node 2 Leader

Prof Wojciech Lipinski

Australian National University

Principal Investigator

Prof Paul Meredith

The University of Queensland

Principal Investigator

Advisory Committee Representative

Prof Gus Nathan

The University of Adelaide

Principal Investigator

Node 4 Leader

Prof Wasim Saman

University of South Australia

Principal Investigator

Node 2 Sub-Leader

Prof John Barry

Queensland University of Technology

Principal Investigator

Node 4 Sub-Leader

Prof David Lewis

Flinders University

Principal Investigator

Node 1 Sub-Leader

Other Key Personnel

Dr John Pye

Australian National University

Node 1 Leader

Prof Hal Gurgenci

The University of Queensland

Node 3 Leader

Prof Bassam Dally

The University of Adelaide

Education Leader

Dr Andrew Beath

CSIRO

Overarching Economic Model Leader

Node 3 Sub-Leader

Ms Sarah Miller

CSIRO

Chief Operating Officer

ASTRI Program Management Committee and other Key Personnel, February 2013

ASTRI Collaboration Map

ASTRI has focussed on the need for collaboration to be genuine. Each project is required to have at least two collaborating partners and the Director has encouraged proposals which have project team members working together to develop the scope and details of projects. Each post-graduate student is also expected to have a co-supervisor from a different collaborating organisation to their home institution. All approved projects meet these requirements.

Nodes and Project Collaboration	CSIRO	ANU	UQ	UoA	UniSA	QUT	Flinders	USASEC
Overarching Economic Model	Lead	x	x	x	x	x	x	x
Node 1: Reduce capital expenditure (CapEX)		Lead					Sub Lead	
Heliostat Cost Down Scoping Study	x	Lead		x	x		x	x
Receiver Performance Scoping Study	x	Lead	x	x			x	x
Node 2: Increase capacity factor	Lead				Sub Lead			
Reliable low-cost PCM thermal storage	x				Lead	x		x
Node 3: Improve efficiency	Sub Lead		Lead					
Supercritical CO2 power block	x		Lead			x		x
Node 4: Add Product Value				Lead		Sub Lead		
Mirror Cleaning	x		x			Lead	x	
Solar Fuels	x	x		*Lead*	x		x	x
Education Program	x	x	x	Lead	x	x	x	x

Collaboration in ASTRI research projects

ASTRI Annual Workshop, ANU, February 2013

Performance against the Program Outcomes

The ASTRI Program Outcomes stem from the USA Solar Energy Collaboration (USASEC) Strategic Research Initiative Objectives and the performance against these are as follows.

Large-scale collaboration on CST across Australia serving as platform for new international linkages

ASTRI is a dedicated and growing Australian CST research community committed to internal and external collaboration. Australia has considerable potential for CST, based on its solar resource and ability to deliver large scale, world class infrastructure. However, Australia cannot reduce the cost of CST technology alone. It must connect with international development led by industry and supported by governments that target accelerated cost reduction pathways through collaboration and the development and commercialisation of new technologies. ASTRI is the platform both for Australian engagement with international developments, primarily the USASEC, but also the European CST research community, and for forging the pathways for the growth of CST in Australia.

The initial period of ASTRI has been devoted to developing a portfolio of well-defined research projects to meet the ASTRI objectives and key performance indicators (KPIs). Noting most of the ASTRI members have not worked together before, each project has at least two collaborating organisations and each post-graduate student within the project is expected to have a co-supervisor from a collaborating organisation.

The ASTRI Director, as the Chairman of SolarPACES and with a wealth of CST research experience and contacts in Europe, is well placed to facilitate new international research linkages. While the ASTRI program has been presented in several international forums, now that research projects have been approved, international linkages need to be consolidated.

Step-change in the commitment of Australian researchers to the success of CST

The commitment of Australian researchers to the success of CST has previously been cyclical and dependent upon funding opportunities. When ASTRI was proposed, only CSIRO and the Australian National University (ANU) had any significant research CST activity and two other ASTRI research partners had CST projects with funding from the Australian Solar Institute, now ARENA.

Prior to ASTRI, CSIRO had 20 full-time staff in the Solar Group focussing on CST research, with a further 13 full-time-equivalent staff contributing specific skills from across CSIRO to predominantly co-investment applied research projects. ANU was seeking to build on its pioneering role and strengthen its research presence in concentrating solar thermal engineering. Through the commitment of ASTRI, ANU has been able to make two senior academic appointments. Within ASTRI, The University of Queensland combines its expertise from UQ Solar (photovoltaic) and the Geothermal Energy Centre of Excellence. The main contribution from The University of Adelaide to ASTRI is in the development of low cost solar fuels, with interests in receiver development and heliostat aerodynamics. The University of South Australia has a strong background in phase change materials for energy storage at ambient temperatures and are moving to high temperature systems for CST. The Queensland University of Technology and Flinders University both bring material science capabilities to ASTRI, together providing expertise in corrosion, nano-coatings and catalysis.

Within ASTRI, a challenge is to deliver both academic qualities in the research, as well as contribute to the cost reduction in CST. It is expected that the academic quality will be delivered through post-graduate research topics, with their academic supervisors being “the glue” with responsibility to ensure relevance of the outcomes to the ASTRI Node targets and ultimately the ASTRI LCOE reductions.

Highly-trained graduates ready to deliver success in CST industries

Prior to ASTRI, there was no dedicated undergraduate concentrating solar thermal technologies degree anywhere in the world. As a multi-disciplinary topic, ASTRI aims to develop course modules that can be flexibly targeted at under-graduates in a range of science and engineering courses, as well as contribute to coursework programs and short courses for post-graduate students.

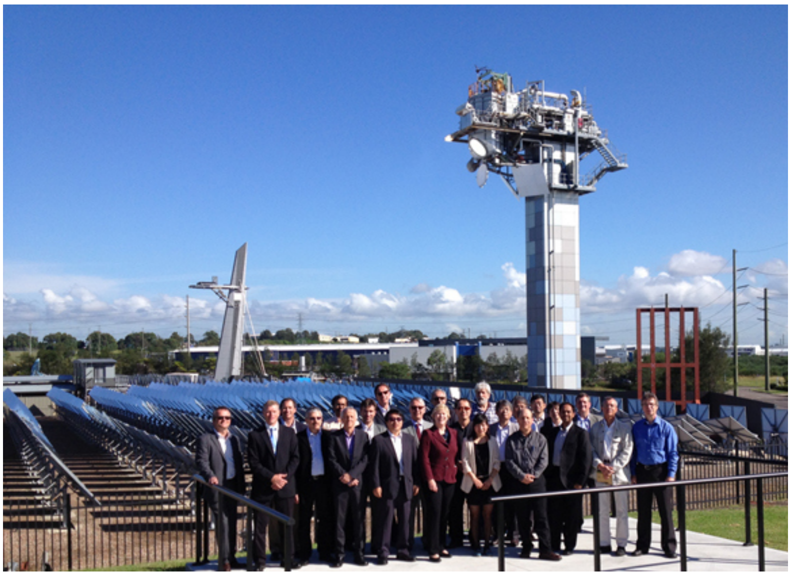
Relevant research outputs: novel technologies, concepts, know-how, publications and patents

A key output of the first four years of ASTRI is to develop plans for a demonstration of the supercritical CO_2 radial turbine for remote area applications on a CSIRO solar tower at Newcastle, which could be the first on-sun testing a supercritical CO_2 turbine in the world. A successful demonstration is expected to lead to a system demonstration with suitable phase change thermal storage, incorporating other heliostat and receiver designs, as well as mirror soiling minimisation concepts.

The key research outputs to date are the two journal publications arising from preliminary dynamic analysis of a simple supercritical CO_2 trough CST system that have guided the development of two approved projects.

Researchers equipped to engage in the science and technology debates that may underpin Government policy towards CST adoption

The ASTRI Overarching Economic Model is intended to inform ASTRI researchers and provide a unifying factual basis upon which researchers are equipped to engage in the science and technology debates. While passionate about their own research, researchers are often ill-equipped to provide informed comment outside their areas of specialty. A key aspect of this is to understand how their specific areas of research will impact on the LCOE, the overall system performance and the added-value that CST technologies bring to the energy marketplace.



The SolarPACES executive committee and CSIRO's Chief Executive, Dr Megan Clark, strike a pose at the Newcastle Energy Centre

Performance against the Key Performance Indicators

The ASTRI Key Performance Indicators (KPIs) were formulated in terms of the ASTRI Objectives and the KPI metrics for 2013 have been met.

Research Quality

Objective: to undertake highly innovative and internationally competitive research with a strategic focus on CST technologies that will lead to breakthroughs in the cost of solar energy

KPI: Number of refereed journal publications

In the preparation and establishment of the ASTRI research program, refereed journal papers have been published by ASTRI researchers that begin to build recognition of ASTRI as a highly innovative and internationally competitive research program. To ensure quality, ASTRI has a publication policy that includes a pipeline for preparation and review. The journal papers published or accepted for publication are listed under “Publications and Presentations”, with a summary of their importance below.

Two papers were on CST supercritical CO_2 systems that deal with fundamental issues concerning dynamics that have implications for future operation and control of such plants. In particular, the findings of the second paper demonstrate the importance of the hot fluid/cold fluid volume ratio on the plant time constants.

In addition, two papers presented at SolarPACES in September 2013 were fully refereed and have been accepted for publication in Energy Procedia. One of these argues that, in developing an experience curve, the number of commercial installations is more important than the cumulative installed capacity. The other paper is a case study for a new heliostat design, and aims to provide directions and to identify opportunities for cost reduction.

KPI: Percentage of joint refereed journal publications

Both of the published refereed journal papers were co-authored by more than one ASTRI partner. The two Energy Procedia papers accepted for publication were authored by only one ASTRI partner, making the percentage of joint refereed journal publications 50%.

US Collaboration

Objective: to participate in significant collaborations with leading U.S. researchers and institutions

KPI: Visits to/from US Collaborators

ASTRI researchers have had a number of visits to and from US collaborators over the course of the year.

Prof Ellen Stechel, from Arizona State University (ASU) attended on Day 1 of the ASTRI workshop in February 2013 as an informal US representative on the Advisory Committee. During the day she provided guidance with a US perspective of the ASTRI program, along with feedback about the program challenges during the end of day review.

Several key US research leaders visited Australia as part of the SolarPACES ExCo meeting in April 2013, allowing ASTRI researchers to interact both formally and informally with US and other international researchers. An example was discussion about potential to collaborate with ASTRI to modify NREL software.

The ASTRI Director was invited to the “SunShot Concentrating Solar Power Program Review 2013”. Wes Stein was based in the US in August and September 2013, visiting NREL, Sandia National Laboratories as well as commercial entities to build science and business relationships. An important aspect of the visits was to review existing ARENA funded projects involving collaboration between CSIRO and the US, general discussions about ASTRI were held, with a specific focus on ASTRI participation in an NREL led SunShot ELEMENTS program.

Prof Ellen Stechel visits ASTRI in Canberra in February 2013

KPI: Number of new projects started with US institutions

ASTRI projects have nominated US participation which needs to be formalised. Examples include:

- Extensions to plant performance modelling related to the Overarching Economic Model
- Access to heliostat costs and designs
- Review of the receiver state-of-the-art
- Research exchange visits related to test methods and exchange of economic modelling data of a reliable low-cost phase change material (PCM) thermal storage
- Potential partnerships on turbine design and testing for the supercritical CO_2 power block
- Experience and evaluation of mirror cleaning concepts
- Strong collaboration interest in solar fuels with Arizona State University and the University of Colorado.

Human Capacity

Objective: to build human capacity in solar research and development by supporting researchers of high international standing as well as the most promising emerging and mid-career researchers

KPI: Number of new staff/postdocs/PhDs recruited

A number of key new staff and five PhD students have been appointed within ASTRI.

Prior to the finalisation of ASTRI, CSIRO announced that Dr Manuel Blanco had been appointed as the Solar Group Leader. Manuel has almost three decades of academic, research and development managerial experience in CST technologies, primarily related to power generation (CSP). He began with CSIRO in January 2013 and immediately assumed the role of ASTRI Director.

Professor Wojciech Lipinski commenced as ANU's new leader in Solar Thermal Engineering in September 2013 and assumed the role of ANU Principal Investigator. Wojciech's expertise includes development of high-temperature processes that utilise concentrated solar radiation for renewable fuel production and power generation. ANU appointed Dr Joe Coventry as a Project Leader of the two Node 1 scoping studies. After completing his PhD in concentrating solar photovoltaic power, Joe spent a decade in research and in commercial projects for concentrating solar thermal power. Most recently ANU has appointed a research assistant to contribute to receiver designs and to the literature review.

Following the approval of the supercritical CO_2 power block project, UQ appointed three PhD students on topics related to turbine development and a PhD student on hybrid cooling. A further UQ PhD student was appointed for the mirror cleaning project.

A further key appointment is Dr Brian Webby (UniSA) on the Overarching Economic Model project. A range of appointments are expected in the near future.

KPI: Accumulative number of post-graduate student completions

PhD students take at least 3 years to complete their studies, the first ASTRI PhD students will be due to complete their studies in 3-4 years time.

Collaboration involving research training

Objective: to strengthen institutional capability by providing high-quality training environments for the next generation of researchers.

KPI: Number of student/staff visits between partner institutions

To promote collaboration, ASTRI has committed to student/staff visits between partner institutions. The Principal Investigators and project teams have met frequently by video conference, resulting in less staff visits between partner institutions. In the future, the number of staff visits between partner institutions may not increase significantly, but student visits and/or exchanges will increase.

Industry engagement

Objective: to partner and engage industry stakeholders to identify and provide pathways for commercialisation of technology.

KPI: Funding from external sources

An example of early stakeholder engagement is an award to The University of Queensland from the Queensland State Government Futures Co-Investment Fund for hybrid cooling research infrastructure that will be used within ASTRI. The hybrid cooling research infrastructure will be used to test power block cooling concepts suited to arid regions where high ambient temperature limits the efficiency of ambient-cooling and where access to abundant water limits the feasibility of wet-cooling. The ASTRI hybrid cooling research is focussed on natural draft dry cooling towers, whereas this grant enables the ASTRI research team to consider a comprehensive solution by investigating hybrid cooling for more common forced-convection cooling towers. Thus this Queensland grant of $1.5M expands the scope of the ASTRI project and will improve the ASTRI project outcome.

Knowledge Transfer

Objective: to facilitate the transfer of knowledge through public education of solar energy technologies and research outcomes and provision of support for policy development.

KPI: Number of conference presentations

In the initial stages of ASTRI, most of the conference presentations and knowledge transfer have been to provide an overview of ASTRI, its objectives and scope. Two poster presentations at SolarPACES were related to the technical and market opportunities within two ASTRI projects. The papers for both these posters were fully reviewed and have been accepted for publication in the journal Energy Procedia. The presentations are listed at the end of this report under Publications and Presentations.

Technical

Objective: to deliver cost reductions and dispatchability improvements to CST in Australia, in terms of LCOE (c/kWh), through improvements in overall annual efficiency, reductions in capital expenditure, increases in capacity factor and minimisation of O&M costs.

ASTRI is committed to reducing the LCOE for CST to 12 c/kWh. In order to demonstrate the technical improvements within ASTRI, a CST plant based on a proven trough technology was defined as the baseline, with an LCOE of 26.5 c/kWh. An ASTRI central receiver tower reference, based on similar specifications for the ASTRI trough baseline, has an LCOE of 22.5 c/kWh. Rather than replace the trough baseline case, this central receiver tower reference system establishes an alternative within which to interpret achievements when developing technology improvements for tower-based activities.

ASTRI is technology agnostic, although sensitivity analyses demonstrate the limited impact that research can have on the proven parabolic trough technology. The significant improvements in energy performance and reductions in cost that ASTRI is targeting require step changes that are unlikely to be met with the proven parabolic trough technology. While some ASTRI projects will provide impacts that are independent of the collector technology that is used, the focus of the research is on central receiver tower technologies. These tower systems allow for the generation of higher temperatures in the heat transfer fluids and the development of low-cost solar collection systems of more flexible design. Higher temperatures are important in allowing use of higher energy density thermal storage systems and high efficiency power blocks, both of which will be necessary to achieve subsequent ASTRI Technical KPIs.

One of the key challenges of the tower technology is that, for large power blocks to be supplied by a single tower, a very tall tower with a large field is required which is perceived as having increased uncertainty and risk of project failure. Within ASTRI, these contingency factors, based on having uncertainty and risk, have been ignored.

ASTRI Trough Baseline	ASTRI Central Receiver Tower Reference
The ASTRI trough baseline is a nominal 100 MW oil parabolic trough plant with 4 hours of molten salt thermal storage, with the reference site being Alice Springs.	The ASTRI central receiver tower reference is a nominal 100 MW molten salt tower plant with 4 hours thermal storage, with the reference site being Alice Springs.
ASTRI has assumed a dry cooling system, to condense the residual steam in the power block back to water, resulting in a realistic power cycle efficiency of 35.2% that is lower than a wet cooling system.	ASTRI has assumed a dry cooling system but because the tower power block operates at a higher temperature than the trough, a slightly higher power cycle efficiency of 37.7% is used.
The energy performance of these standard CST systems were determined by using the NREL System Advisor Model (SAM)	
The costing was prepared based on the cost values used in the Australian Energy Technology Assessment (BREE, 2012*)[§]	
The LCOE calculation used a standard engineering cost assessment methodology, with a discount factor of 7%, in order to remove the consideration of complex financing arrangements.	

*BREE (2012) "Australian Energy Technology Assessment, 2012" http://www.bree.gov.au/publications/aeta.html

Comparison of Trough Baseline and Central Receiver Tower Reference System

The energy and cost characteristics of the trough baseline and tower reference case have been compared.

It should be noted that the tower technology is not fully commercially proven and would have a higher risk rating that would result in commercial analyses having additional contingency factors being applied.

In all of the characteristics, the tower plant matches, or is better than, the performance of the trough case. Operating and maintenance costs for tower systems are shown as equivalent to those of trough systems, but it should be noted that these are quite poorly quantified for tower systems and it is common to assume that these costs are approximately equal to those of trough systems. The research being conducted in

Node 4 of ASTRI will have a need to establish these O&M costs in a more detailed manner. The capital cost ($/kWe) breakdown for the two plants indicate that there are differences in the ways costs are incurred on the two processes that can influence the benefits of different types of research.

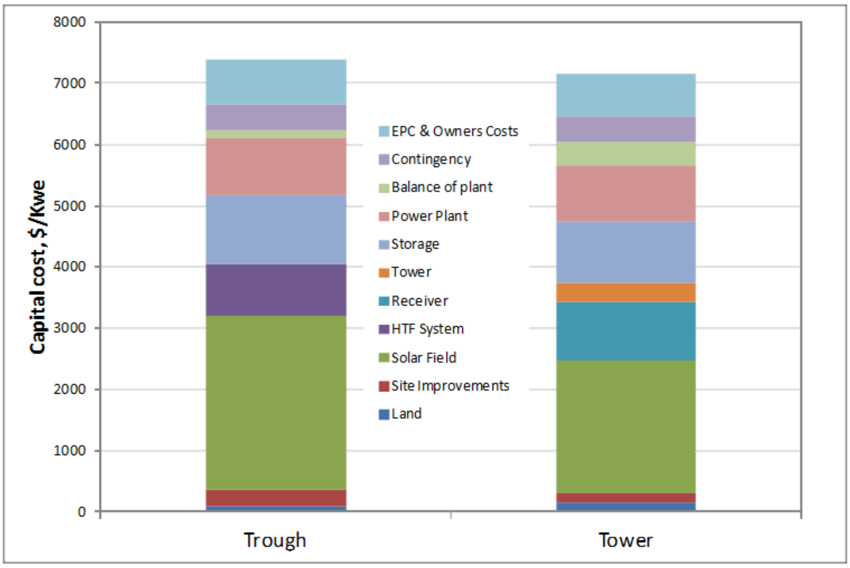
Comparison of characteristics of baseline trough and central receiver tower reference systems

Characteristic	Units	Trough	Tower
Energy Characteristic			
Plant Capacity (Net)	MW	100	100
Plant Capacity Factor	%	36.1	41.3
Thermal Efficiency	%	13.0	13.9
Cost Characteristic			
2012 Capital Cost[§]	$/kW	7380	7157
Fixed O&M cost	$/MW/y	67300	67300
Variable O&M cost	$/MWh	4	4
LCOE	**c/kWh**	**26.5**	**22.5**

When changing from parabolic trough to central receiver towers, it is expected that the field efficiency will decrease and the capacity factor increase due to the different characteristics of the collectors.

Some of these changes are then offset by other components of the system, such as a power block of higher efficiency.

This makes the overall energy performance changes difficult to predict and requires some expertise to interpret.



Comparison of capital cost[§] breakdown for trough and tower systems

Specific Research and Education Activities of the Program

Overarching Economic Model Project

Project P01	Project to develop overarching economic model

Project leader:

Dr Andrew Beath (CSIRO)

Collaborating & Contributing Institutions:

CSIRO

Australian National University

University of Queensland

University of Adelaide

University of South Australia

Queensland University of Technology

Flinders University

NREL

Timeframe:

May 2013 – May 2016

CST Need

Individual innovations within CST can offer real overall improvements to the efficiency of the plant. However, it is not possible to comprehensively value the improvements made or to understand the input data for research in a particular section of the plant without having an overall model which incorporates the cost and performance of the plant.

Approach and Innovation

An overarching economic model of a concentrating solar thermal plant is being developed to allow the overall cost of solar thermal power to be predicted based on varying changes made within the system. It also provides data for variables within the system which depend on other constraints. This offers invaluable support to the other projects in ASTRI which examine the potential to make improvements to various parts of the plant. This support is both through the provision of inputs for their work as well as showing how the results the individual project will affect the overall LCOE. The objectives of the project are:

- Production of initial baseline cost and performance using existing models ;
- Preparation of standard input data sets;
- Development of the central financial model for distribution to ASTRI participants;
- Sensitivity analysis to highlight targets for improved research effectiveness, including preparation of separate cost and performance predictions for the major components of the plants;
- Provision of regular updates extending capability and automating costing for standard components;
- Generation of annual performance data to show progress against LCOE KPIs.

To achieve these objectives a combination of models are used, including the System Advisor Model (SAM) developed by NREL, to establish the overarching economic model. The modelling methods used in various Australian and International studies are compared and a model framework established. This framework is set up to allow input from various modelling tools used by other ASTRI projects. Therefore, this project involves a collaborative effort to develop the input data for the model. This involves visits to the collaborating institutions to ensure consistency in methods to establish cost and performance data.

Outcomes and Benefits

This project is specifically targeted at providing advice to the ASTRI projects and Nodes through identification of high value targets that can assist in the impact of research on the ASTRI LCOE objective. Solar fuels and poly-generation projects have a more complex alignment.

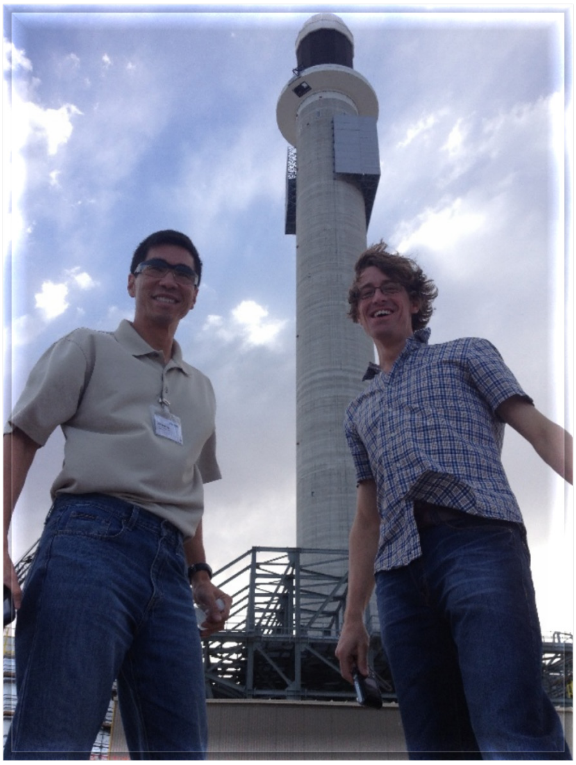
Work in this project has led to refinement of the ASTRI parabolic trough base case and the development of a reference case for a central receiver tower system. Work is underway in the exergy (useful energy) analysis of these cases.

Node 1: Reduce Capital Expenditure

Node 1 Leader: **Dr John Pye (ANU)** **Node 1 Sub-Leader:** **Professor David Lewis (Flinders)**

The main cost involved in CST plants is the capital expenditure (CapEx) to design, develop and construct all the components and systems of the plant. This expense is compounded by the emerging nature of the CST industry and perception of risk which can reduce investment opportunities. By reducing the capital expense and proving the reliability of CST component and systems technologies, the technical and investment risk is reduced, which will improve bankability and effectively reduce CapEx. With this in mind, it is the aim of this node to make improvements in CST design to reduce the CapEx. This objective is being achieved by modelling, design, and industry engagement to assess attractiveness and feasibility of option. This will lead to the development of a small pilot scale demonstration in conjunction with industry.

There are some key leverage points to reducing the capital expenses which were identified following robust discussion on the breadth of possibilities, the broad interest and the significance to meeting the overall ASTRI targets. These include the cost of the solar field and the performance of the receiver. Scoping studies have therefore been conducted in the area of improved heliostats, and another in the area of high-temperature receivers, which are outlined below. These projects provide a basis to determine project areas that will have the greatest impact and innovation in reducing CapEx. This approach avoids 'unfocussed' efforts in new concept development and provides a consensus between institutions of where there are promising research opportunities for investigation in subsequent ASTRI projects.



Cliff Ho (Sandia) and John Pye (ANU)
Crescent Dunes field trip, Septmber 2013

Project P11 — Heliostat Cost Down Scoping Study

Project Leader:

Joe Coventry (ANU)

Collaborating & Contributing Institutions:

ANU

Flinders University

CSIRO

University of Queensland

University of Adelaide

University of South Australia

Queensland University of Technology

Sandia National Laboratory

NREL

Project Duration:

2013-2014

CST Need

It is expected that improvements in heliostat fields can provide a leverage point to reduce the overall LCOE of CST due to the substantial capital and operating costs associated with heliostat fields, along with the numerous variables in heliostat field design that make up this cost. Therefore, it is necessary to identify and prioritise the factors that contribute to the cost of heliostat fields to find potential improvements.

Approach and Innovation

This project incorporates a preliminary activity targeting the reduction of capital expenditure across an entire CST solar field and involves input from many key collaborators in ASTRI. The scoping study provides directions and it identifies opportunities for heliostat cost reduction activities to be carried out during subsequent ASTRI projects that both progress the state-of-the-art and have the potential to lead to dramatic solar field cost reduction, consistent with the LCOE targets set under the program. The study involved the following actions:

- Review of the state-of-the-art in heliostat design;
- Work collaboratively with the Overarching Economic Modelling project to establish both baseline costs and target costs for heliostats;
- Generate ideas for, and discussion of, key principles in advancing the state-of-the-art in solar field and heliostat design consistent with ASTRI target costs, including ASTRI stakeholder consultation;
- Recommend promising concepts for future projects to be carried out as part of the Node 1 capital expenditure reduction activities.

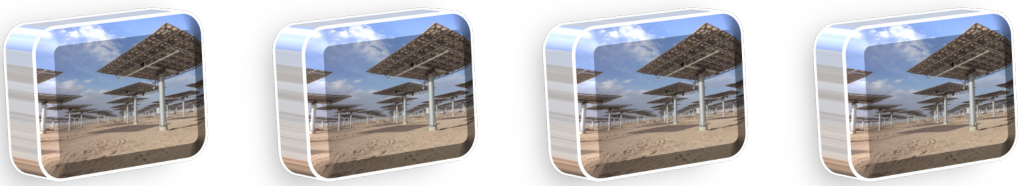
The project sourced material from publically available documents, unpublished research by ASTRI members and interviews with experts in the field.

Outcomes and Benefits

The project team reviewed 15 heliostat designs in terms of their

- Current and target costs
- Leverage of performance
- Importance of O&M costs
- The influence of solar field layout
- Manufacturing and assembly
- Heliostat size
- Wind loads
- Reflector technologies
- Structural mirror panels
- Autonomous heliostats
- Alternative solar tracking systems
- Actuations systems

to propose 4 design concepts to develop in the subsequent research project.



Heliostats at Crescent Dunes, September 2013

Project P12 Receiver Performance Scoping Study

Project Leader:

Joe Coventry (ANU)

Collaborating & Contributing Institutions:

ANU

Flinders University

CSIRO

University of Adelaide

Sandia National Laboratory

Project Duration:

2013-2014

CST Need

Improvements in receiver efficiency will lead to a reduction of solar field capital expenditure because less solar energy would be necessary to provide the optimal energy requirements for the CST.

Approach and Innovation

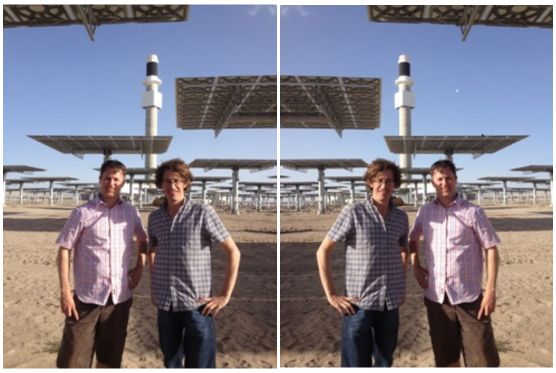
This project incorporates a preliminary activity targeting reduced capital expenditure across an entire CST solar field and involves input from many key collaborators in ASTRI. The scoping study provides direction and identifies opportunities for future ASTRI activities aimed at improving the performance of receivers for CST systems to be carried out during subsequent ASTRI projects that both progress the state-of-the-art and have the potential to lead to dramatic solar field cost reduction, consistent with the LCOE targets set under the program. The study involves the following actions:

- Summarise recent CST industry studies that forecast technology developments across all major CST system configurations, to provide context to the receiver review and guidance to priority areas;
- Review the state of the art in receiver design, which involves incorporating previous reviews that are considered in-depth and currently relevant;
- Carry out high-level system performance analysis to quantify and compare the potential performance benefits of a shortlisted selection of receiver designs;
- Undertake generation of ideas for, and discussion of, key principles and challenges in advancing the state-of-the-art in receiver design consistent with ASTRI KPIs, including ASTRI stakeholder consultation;
- Recommend promising concepts for future projects to be carried out as part of the Node 1 capital expenditure reduction activities.

The project sources material from publically available documents, unpublished research by ASTRI members and interviews with experts in the field.

Outcomes and Benefits

By April 2014, the project will review receiver performance, which has impact on both reduction of solar field Capital expenditure and net efficiency, both of which are key elements to achieving the LCOE targets. Work in this project has currently collated a wide variety of receivers, noting the heat transfer properties, associated energy losses and other characteristics. There is also work underway to establish an evaluation tool to aid the decision as to what designs should be further researched.



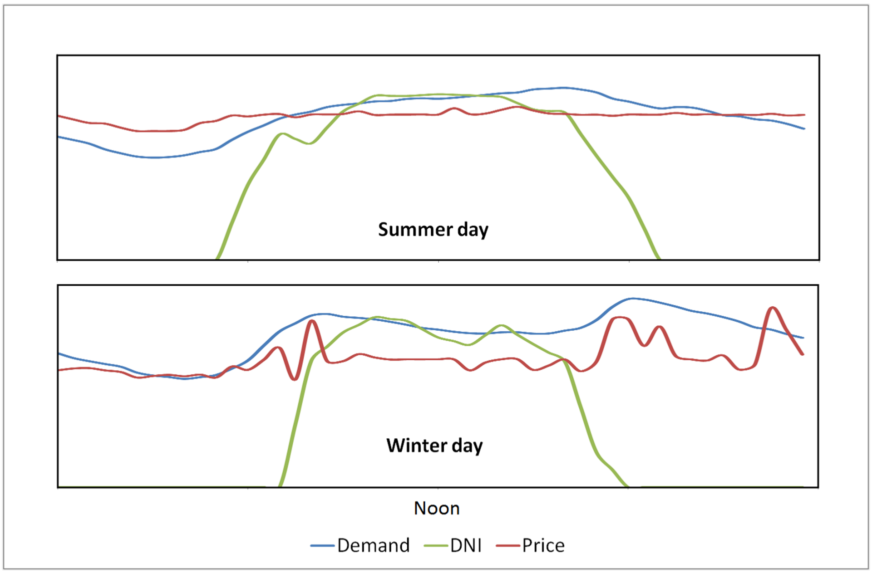
Joe Coventry and John Pye (ANU)
Crescent Dunes field trip, September 2013

Node 2: Increase Capacity Factor

Node 2 Leader:	**Mr Wes Stein (CSIRO)**	**Node 2 Sub-Leader:**	**Professor Wasim Saman (UniSA)**

A critical determinant in the LCOE of weather-dependant generators is the capacity factor, or how many hours of the year the power block or turbine can operate to produce electricity that can be sold into the grid. The capacity factor of a CST plant can be increased by the inclusion of thermal storage, hybridisation, alternative field designs and adapting overseas technologies to Australian conditions. The development of cost effective thermal storage technologies is considered a prize that can differentiate CST from other weather dependent generators. The aim of this Node is, therefore, to develop the materials needed for low cost storage and analyse the system impact benchmark against overseas technologies and create the unique Australian value proposition. It is worth noting that the appropriateness of the storage depends on the other parameters of the CST system which determine the temperature requirements of the storage system.

Both thermophysical and thermochemical energy storage are studied in this node of research. Current research in this node is focussing on thermophysical storage which is detailed below. Thermophysical storage involves storing energy in the form of latent heat or sensible heat. Sensible heat can involve liquid, solid or dual media materials, including molten salts and solid blocks such as concrete and carbon. Latent heat storage involves phase change materials (PCM) and does not require temperature change. Thermochemical energy storage is an emerging technology with the potential to provide high density energy storage. The technology is based on thermochemical cycles or looping in which predominantly gaseous and/or solid materials undergo reversible reactions to store and release heat. It has been recognised that potential revolutionary leaps are possible with thermochemical storage and may therefore be highly interesting to ASTRI.



Resource storage and dispatch opportunity to meet demand and price

Project P22 — Reliable low-cost phase change material thermal storage systems

Project Leader:

Wasim Saman (UniSA)

Collaborating & Contributing Institutions

University of South Australia

CSIRO

Queensland University of Technology

NREL

Project Duration:

2013-2016

CST Need

One of CST's advantages is the ability to store thermal energy within the power plant. However, there is a lack of research into the best technologies for high temperature thermal storage which would be applicable for CST. Currently, the most common form of thermal storage in commercial CST systems uses sensible heat materials in the form of synthetic oil and molten salt. In contrast, systems that utilise thermo-chemistry, phase change materials and other sensible heat materials are still under development. Phase change material (PCM) thermal storage systems could offer a low-cost and reliable method for energy storage. However, most research on PCMs has been for low temperature applications and further research is needed to understand its potential for CST.

Approach and Innovation

The research proposed here aims to build on current UniSA research to develop a practical PCM storage system costing less than $25/kWh(th). This involves the investigation of a thermal storage system which uses encapsulated PCM, and comparing it to the PCM storage system types that use bulk PCM currently being investigated by UniSA. The project involves the following actions:

- Develop new methods for measuring the thermophysical properties of PCMs at high temperature;
- Evaluate compatibility of construction materials and their inherent corrosion;
- Develop new PCMs;
- Develop a computer model of a PCM thermal storage system which uses encapsulated PCM;
- Construct sample encapsulations with PCMs and carry out cycling tests at high temperatures;
- Carry out extensive computer simulations for the thermal performance of the various types of thermal storage systems with different PCMs and construction materials;
- Select the two most promising PCM storage system types, by considering reliability and cost, for prototype construction and testing in the high temperature test facility.

This investigation includes various PCMs, construction materials, reliability and the costs for all the storage system types.

Outcomes and Benefits

The enhanced thermal storage systems developed through this project will maximise the reliability and operational flexibility of the storage system, reduce the cost of materials and maintenance, and therefore improve the overall LCOE of the CST plant. The additional advantages of PCM thermal storage, including the ability to store heat at constant temperature, will allow optimisation within other processes, such as the power block, and can therefore offer 'flow on' improvements to the efficiency throughout the plant, which will further reduce the LCOE.

This extensive project involves a number of students and academics, with high levels of collaborations with US partners. It therefore embodies ASTRI's emphasis on building relationships between institutions, knowledge sharing and developing human capacity.

Node 3: Improve Efficiency

Node 3 Leader:	Professor Hal Gurgenci (UQ)	Node 3 Sub-Leader:	Dr Andrew Beath (CSIRO)

CST plants involve a range of interacting processes and systems to deliver electricity and other products derived from the heat of the sun. Due to the number of processes and the systems that link them, it is possible to make efficiency improvements throughout the CST plant by researching various leverage points in the system and examining how they affect other requirements and efficiencies of the plant. Such points have been identified by ASTRI and subsequently this node of research focuses on improved efficiency through novel high-temperature cycles, advanced dry and hybrid condensers, receivers capable of high flux and/or high temperatures, and poly-generation.

To achieve optimal efficiencies it is necessary to undertake systematic analysis of the inherent tradeoffs in internal systems and operation. It is also important to take into consideration any extra costs involved in improving the efficiency of the CST to determine whether the efficiency will result in a reduced LCOE. The inaugural project in this node is aiming to develop and demonstrate supercritical CO_2 cycles. The project scope includes development of a supercritical CO_2 turbine and hybrid cooling technologies for air cooling. Additional proposals are being developed to explore other advanced power cycles. There is strong collaboration within this node between ASTRI partners in order to investigate the materials and their performance under realistic cycles.

The University of Queensland High Pressure Turbine Test Rig with Andrew Rowlands (L) and Carlos Ventura (R)

Project P31A Supercritical CO_2 Power Block

Project Leader:

Hal Gurgenci (UQ)

Collaborating & Contributing Institutions:

University of Queensland

CSIRO

Queensland University of Technology

Sandia National Laboratory

NREL

The University of Texas

Project Duration:

2013-2016

CST Need

The use of a supercritical CO_2 (sCO_2) power cycle is aimed at improving efficiencies. Higher efficiencies will indirectly reduce the unit costs. The system is also expected to directly reduce capital cost because sCO2 equipment is much more compact and simpler. These benefits will be achieved through the following two mechanisms:

- Supercritical CO2 is a more appropriate fluid for high-temperature CST applications with significant efficiency benefits.
- Supercritical CO2 power plants also can be built at smaller sizes (down to 250-kWe but preferably in the range of 1-10MWe) without significant cost and efficiency penalties.

The second point offers a fast commercialisation path in Australia by being able to serve relatively small remote power generator market. This path offers a third mechanism for cost reduction.

Approach and Innovation

This project is developing technologies that are both enabling and proof-of-concept, which lead to a detailed Commercial Demonstration Plant (CDP) proposal using sCO_2. To achieve this, there are staged goals towards this overall objective, with gateposts and decision points following each goal achievement. The size and the target site for the commercial demonstration plant are to be determined and depend on the client's choice, availability of funding and commercial partnerships, but it is expected to be small to medium scale (1-10 MWe) to suit a radial turbine geometry. Both tower and linear Fresnel receiver (LFR) systems are being modelled and considered in this project as possible supercritical CO2 system alternatives for the CDP. The final choice depends on the manufacturing partnerships and the client's choice. It may be suitable to develop the project as a foundation demonstration within a Solar Thermal Research Park because this may increase funding opportunities.

The project involves the following actions:

- Design leading to demonstration sCO2 turbines:
  - Construct a small demonstration turbine for a CSIRO Central Receiver;
  - Establish partnership with the selected supercritical turbine manufacturer;
  - Design a turbine for the CDP (in conjunction with a manufacturer);
- Design and demonstrate a cooling system for sCO2 suitable for hot arid climates;
- Choose materials for the above in terms of operational requirements and corrosion resistance.

Outcomes and Benefits

Successful completion of this project will have favourable impact on all ASTRI technical KPIs. The project will reduce the LCOE, increase the overall efficiency, reduce the unit Capital Expenditure, increase the capacity factor without increasing the LCOE and finally minimise the O&M costs due to supercritical CO_2 systems, which have an inherent compact design and are amenable to fully automated operation.

Node 4: Add Product Value

Node 4 Leader:	**Prof Gus Nathan (Adelaide)**	**Node 4 Sub-Leader:**	**Professor John Barry (QUT)**

With the emergence of the concentrating solar thermal (CST) industry in Australia, it is important to capitalise on the various advantages CST can bring beyond electricity generation. Australia has unique local opportunities for applications in CST for intensive industrial processes and resources. Therefore, adding product value will arise from minimising operating and maintenance (O&M) costs, as well as developing new, high value, solar thermal products.

While ASTRI focuses primarily on electricity generation, its secondary emphasis on solar chemistry is to be able to produce fuels or provide a solar boost to Australian mineral and energy industry processes. A preliminary project within ASTRI is being finalised to perform techno-economic modelling on the development solar fuels using solarised gasifier reactors and prioritise future ASTRI research.

CST plants can also increase in value by lowering their O&M costs, which are currently substantial. This node therefore examines how to drive these costs down through design improvements based on experience and know-how. This involves dissecting the O&M costs with the industry collaborators and setting benchmarks for the materials development and also to set benchmarks for best practice within the industry. The key areas of research identified for ASTRI are self-cleaning reflectors, corrosion control and automation of performance monitoring for O&M scheduling.

Queensland University of Technology Dust-Monitoring equipment, Collinsville, Queensland

Project P41 Mirror Cleaning

Project Leader:

John Barry (QUT)

Collaborating & Contributing Institutions:

Queensland University of Technology

Flinders University

CSIRO

University of Queensland

Project Duration:

2013-2016

CST Need

The most common effect of dirt particles on mirror surfaces is to deflect or scatter incident light which has been shown to be site-specific. For a concentrating collector, even small deflection will cause the reflected light to miss the receiver and not be collected. At some sites, the specular reflectance is maintained at a high level, while at others, losses in reflectance of over 70% have been observed in less than three months. It is therefore necessary to develop a system for efficient and regular cleaning of collector surfaces to maintain high reflectance.

Approach and Innovation

This project involves developing cost-effective cleaning systems for CST plants by combining theoretical modelling with experimental validation for non-contact spray-cleaning systems and for various dust load/surface types. To achieve this, the project involves the following actions:

- Establish a baseline of cleaning costs by reference to experience in solar plants overseas and in relation to conditions relevant to Australia
- Evaluate industrial spray nozzle technologies, using CFD to optimise the stand-off distances, pressure and flow rate, impact of temperature and effectiveness chemical addition
- Undertake real-time dust monitoring, collection and characterisation at proposed CST sites
- Explore surface properties and surface coatings based on ophthalmic abrasion resistant coatings with silica nanoparticles, which provides a very durable rough surface.

Outcomes and Benefits

This project has significant potential to decrease the operating and maintenance costs of the heliostat field. It will also contribute to the efficiency of the heliostat field by reducing the scattering of light due to unclean heliostats. The importance of building relationships with industries involved in collector development and use has been identified as a key consideration early in this project. Not only is this critical for sourcing data on the cost and running of mirror cleaning, it also offers a potential partnership through the use of their facilities and the benefits the industry can gain to their cleaning system.

Education Program

Project P02	Project to develop a CST education program

Program Leader:

Professor Bassam Dally

Collaborating & Contributing Institutions:

All ASTRI partners

Program Duration:

2013-2016

Need addressed:

In order to strengthen Australia's ability to provide efficient and affordable concentrating solar thermal power it is necessary to build human capacity in concentrating solar thermal power research and development. This requires the provision of high quality training environments for the next generation of CST researchers and professionals.

Approach and Innovation:

The program involves developing specialised, current and advanced educational material in concentrated solar thermal technology. This material will be shared among participating institutions and the professional practitioners in general and used to improve student access to concepts and innovations relevant to CST. Through the exposure of students and professionals from a range of disciplines to CST, they will be given the opportunity to become familiar with and to gain an interest in work in this field.

Discussion with key stakeholders has identified the need to broaden the educational base from concentrated solar power and other technologies. This broadening allows institutions to cover a wider range of concentrated solar thermal energy usage while still addressing, in detail, electricity generation in dedicated specific modules. Worth noting is that the modules will cover collection, concentration and utilisation of solar energy. Utilisation can be in different forms and may also include hybridisation, combined cycles or other processes of which power generation is only one. Hence the move to cover a wider base has very little impact on the CST education, while it has the advantage of broadening the students' interest in solar energy. With this in mind, the project incorporates the following actions:

- Develop educational modules on CST tailored to undergraduate and Masters by course-work students;
- Utilise e-learning as a transferable and cost-effective medium to deliver content;
- Incorporate invited talks from key local and international researchers, especially from US partners
- Develop and share design of, and educational support material for, a range of student laboratory experiments ('practicals') on topics in CST;
- Offer intensive courses to engineers as part of their professional development.
- Increase interest in CST research;

Modules are being developed with a range of teaching tools including course notes, video material, projects, laboratory experiments, tutorial questions and quizzes. Each module is being designed to be the length of one week of a conventionally lectured course (equivalent to two hours of spoken material and exercises).

Outcomes and Benefits

The education program will provide skilled students, graduates and professionals for research in the final years of ASTRI as well as for more general research, development and implementation of CST in Australia. The collaboration and sharing of the institutions involved will also enhance relationships between them, and lead to best-practice in solar thermal education being spread across a number Australian universities and institutions.

Knowledge Sharing Activities

The knowledge sharing activities involve both promotional communication activities and dissemination of research goals and results by the researchers.

Communication Activities

The launch of ASTRI in December 2012 was supported by CSIRO with a dedicated ASTRI media release and the creation of web-pages at www.csiro.au/astri. Each of the universities also made announcements about their involvement in ASTRI, including posting on their websites.

In February 2013, CSIRO issued a further media release announcing the commencement of Dr Manuel Blanco, a renowned international solar expert, as Solar Group Leader within CSIRO and as the Director of the ASTRI Program. Extensive national (and international) media coverage was gained, including national ABC radio, the Sydney Morning Herald and The Canberra Times. Solar Progress and Solar Australia also covered Dr Blanco's commencement.

A communications working group was formed with members from the ASTRI Program Management Committee. The group developed an initial communications strategy for ASTRI, which included pursuing a dedicated website and branding. The strategic communication leadership for ASTRI is provided by CSIRO and the intention is to include communication support from the universities.

Dissemination of Public Research

CSIRO has provided information to the general public via www.csiro.au/astri[1] which provides a snapshot of ASTRI covering the research program, education and students, and our partners. As the research program develops, more comprehensive web-pages are being created.

ASTRI funded postdoctoral fellowships and PhD scholarships based at CSIRO's National Solar Energy Centre in Newcastle were advertised at www.csiro.au/astri, providing some details of the direction of ASTRI's research. Several higher-degree research students and postdoctoral fellows from within the ASTRI partners participated in the ASTRI Annual Workshop in February 2013 and project development, giving them an opportunity to develop their research skills in a collaborative team environment.

The publication of results at this early stage of ASTRI are listed in Publications and Presentations and described in the performance against the Key Performance Indicators. This highlights:

- Two papers on CST supercritical CO_2 systems fundamental issues concerning dynamics
- Two poster papers presented at SolarPACES related to the technical and market opportunities within two ASTRI projects

and presentations at key Australian and international CST events:

- First Australian Workshop on Solar Thermal Chemical and Industrial Processes, Adelaide University, 7-Feb-2013
- SolarPACES, Newcastle, 17-Apr-2013
- Solar 2013 Conference and Expo, Melbourne Convention Centre, 24-May-2013
- Solar Solutions: the future of concentrating solar power in Australia: transitions and benefits, Institute for Sustainable Futures, UTS, Sydney, 24-Jun-2013, and
- SolarPACES 2013, Las Vegas, 19-Sep-2013.

[1] This site will continue with a link to www.astri.org.au

Publications and Presentations

Publications

Singh, R., Miller, S.A., Rowlands, A.S., Jacobs, P.A. "Dynamic characteristics of a direct-heated supercritical carbon-dioxide Brayton cycle in a solar thermal power plant" Energy 50 (2013) 194-204

Singh, R., Miller, S.A., Rowlands, A.S. "Effects of relative volume-ratios on dynamic performance of a direct-heated supercritical carbon-dioxide closed Brayton cycle in a solar-thermal power plant" Energy 55 (2013) 1025-1032

Gurgenci, H. "Supercritical CO2 cycles offer experience curve opportunity to CST in remote area markets" submitted to Energy Procedia

Coventry, J. and Pye, J. "Heliostat cost reduction – where to now?" submitted to Energy Procedia

Presentations

Blanco, M. J. "Current status of CST" First Australian Workshop on Solar Thermal Chemical and Industrial Processes, Adelaide University, 7-Feb-2013

Blanco, M. J. "ASTRI Overview" SolarPACES, Newcastle, 17-Apr-2013

Blanco, M. J. "Solar Thermal's Potential" Solar 2013 Conference and Expo, Melbourne Convention Centre, 24-May-2013

Miller, S.A. "ASTRI and CSP Overview" Solar Solutions: the future of concentrating solar power in Australia: transitions and benefits, Institute for Sustainable Futures, UTS, Sydney, 24-Jun-2013

Blanco, M. J. "Overview of CSIRO & ASTRI" EUROTHERM Seminar No. 98 - Concentrating Solar Energy Systems, 7-Jul-2013

Gurgenci, H. "Supercritical CO2 Cycles Offer Experience Curve Opportunity to CST in Remote Area Markets" Poster Session 2, SolarPACES 2013, Las Vegas, 18-Sep-2013

Coventry, J. "Heliostat Cost Reduction – Where to Now?" Poster Session 2, SolarPACES 2013, Las Vegas, 18-Sep-2013

Blanco, M. J. "Plenary: Global CSP Initiatives" SolarPACES 2013, Las Vegas, 19-Sep-2013

ASTRI People

ASTRI Office

Name	Role
Dr Manuel Blanco	Director
Ms Sarah Miller	Chief Operating Officer
Ms Corinne Fisher	Administration

CSIRO Business Support

Name	Role
Ms Brooke Horton	Finance
Ms Gail Fulton	Legal
Mr Bernard Norton	Business Development
Ms Linley Davis	Communications
Ms Sabrina Makaroff	Project Support

CSIRO Researchers

Name	Role
Mr Wes Stein	Principal Investigator Node 2 Leader
Dr Andrew Beath	Node 3 Sub-Leader
Dr Jin-Soo Kim	Node 1 Researcher
Dr Yanping Sun	Node 2 Researcher
Dr Jim Hinkley	Node 4 Researcher
Dr Sameer Khare	Researcher
Mr Alex Burton	Researcher

ANU Researchers

Name	Role
Prof Wojciech Lipinski	Principal Investigator
Dr John Pye	Node 1 Leader
Dr Joe Coventry	Project Leader
Mr Greg Burgess	Researcher
Mr Charles-Alexis Asselineau	Research Assistant

UQ Researchers

Name	Role
Prof Paul Meredith	Principal Investigator
Prof Hal Gurgenci	Node 3 Leader
Dr Peter Jacobs	Research Supervisor
Dr Kamel Hooman	Research Supervisor
Mr Mostafa Odabaee	PhD Student
Mr Qin (Jason) Kan	PhD Student
Mr Mohsen Modirshanechi	PhD Student
Mr Hosein Sadafi	PhD Student
Mr Shengzhe Yu	Masters Student

UA Researchers

Name	Role
Prof Gus Nathan	Principal Investigator Node 4 Leader
Prof Bassam Dally	Education Program Leader
Dr Peter Kalt	Acting Education Officer
A. Prof Chris Doonan	Research Supervisor
A. Prof Peter Ashman	Research Supervisor
Dr Maziar Arjomandi	Research Supervisor

UniSA Researchers

Name	Role
Prof Wasim Saman	Principal Investigator Node 2 Sub-Leader
Dr Frank Bruno	Research Supervisor
Dr Colin Hall	Research Supervisor
Dr Brian Webby	Research Fellow

QUT Researchers

Name	Role
Prof John Barry	Principal Investigator Node 4 Sub-Leader
Mr Francesco Anglani	Research Assistant

Flinders Researchers

Name	Role
Prof David Lewis	Principal Investigator Node 1 Sub-Leader
Dr Jon Campbell	Researcher

Financial Summary

The following is a financial summary for the relevant reporting period (1-Dec-2012 to 31-Oct-2013) and also for the Program overall. Accounting in ASTRI is on a cash basis as this was the preferred method by all collaborators.

Total income with breakdown by funding source

Income by funding source	1-Dec-2012 to 31-Oct-2013	Program overall
Grant funding (ARENA)	$750,000	$750,000
Collaborator contributions	$1,230,784	$1,230,784
TOTAL CONTRIBUTIONS	$1,980,784	$1,980,784

Total expenditure with breakdown by heads of expenditure

Heads of expenditure	1-Dec-2012 to 31-Oct-2013	Program overall
Salaries	$1,953,138	$1,953,138
Equipment	$34,787	$34,787
Materials	$69,271	$69,271
Sub-contract	$0	$0
Travel	$76,235	$76,235
Other	$34,655	$34,655
TOTAL EXPENDITURE	$2,168,086	$2,168,086

Statement of financial performance

Financial summary	1-Dec-2012 to 31-Oct-2013	Program overall
Total contributions	$1,980,784	$1,980,784
Total expenditure	$2,168,086	$2,168,086
OPERATING PROFIT (LOSS)	($187,302)	($187,302)

Declaration:

I hereby certify that the above statement covering the period from commencement to 31 October 2013 represents the financial transactions fairly and is based on proper accounts and records.

Signature:

Cindy Digby BCom MAcc CPA
Finance Manager, Energy Flagship
Date: 27th March 2014

Shortened forms

AEMO	Australian Electricity Market Operator
AETA	Australian Energy Technology Assessment
ANU	Australian National University, Canberra
APA	Australian Postgraduate Award
ARENA	Australian Renewable Energy Agency
ASTRI	Australian Solar Thermal Research Initiative
ASI	Australian Solar Institute
ASU	Arizona State University
AUSTELA	Australian Solar Thermal Electricity Association
BAU	Business as Usual
BREE	Bureau of Resources and Energy Economics
CapEX	Capital expenditure
CFD	Computation Fluid Dynamics
CST	Concentrating Solar Thermal technologies
CSP	Concentrating Solar Power
CRADA	Collaborative Research and Development Agreements with US National Laboratories
CWG	Communications Working Group
DIISRTE	Department of Industry, Innovation, Science Research and Tertiary Education
DNI	Direct Normal Irradiance
DoE	Department of Energy
DOI	DOI is the Digital Object Identifier where replacing "doi:" by "http://dx.doi.org/ provides a web link
DRET	Department of Resource, Energy and Tourism
ELEMENTS	US DOE SunShot CSP: ELEMENTS funding opportunity for engineering new thermochemical storage
EPC	Engineering Procurement Company
EPRI	Electric Power Research Institute
ESTELA	European Solar Thermal Electricity Association
FOAs	Funding Opportunity Announcements
GW	Gigawatt
HDR	Higher degree research
HTF	Heat transfer fluid

IP	Intellectual Property
IPCC	International Panel on Climate Change
KPI	Key Performance Indicator
kW	Kilowatt
kWh	Kilowatt-hour
LCOE	Levelised cost of electricity
MENA	Middle East and North Africa
Megawatt	Megawatt
NREL	National Renewable Energy Laboratory
OECD	Organisation for Economic Co-operation and Development
O&M	Operation and maintenance
PCM	Phase Change Material
PV	Photovoltaic Solar Cell
QUT	Queensland University of Technology
SAM	System Advisor Model developed by NREL
SNL	Sandia National Laboratories
SRI	Strategic Research Initiative
UA	The University of Adelaide
UF	Flinders University [of South Australia]
UniSA	The University of South Australia
UQ	The University of Queensland
USASEC	USA Solar Energy Collaboration

Glossary

Australian Electricity Market Operator (AEMO) – Australia's National Energy Market operator

Angle of incidence – the angle that a ray of sun makes with a line perpendicular to a surface. For example, a surface that directly faces the sun has a solar angle of incidence of zero, but if the surface is parallel to the sun (for example, sunrise striking a horizontal rooftop), the angle of incidence is 90°.

Base load – the average amount of electric power that a utility must supply in any given period.

Capacity factor – the fraction of a period, normally a year, that a plant operates at an equivalence to full capacity

Capital expenditure (CapEX) – the monetary or financial cost associated with long-term investment in physical assets, buildings or equipment.

Concentrating solar thermal (CST) – solar energy conversion systems characterised by the optical concentration of solar rays through an arrangement of mirrors or lenses, to create heat for process and chemical energy systems

Concentrating solar power (CSP) – solar energy conversion system characterised by the optical concentration of solar rays through an arrangement of mirrors or lenses, used to heat liquids or gases, which are then used to generate electrical power.

Direct Normal Irradiance (DNI) – synonym for beam radiation, the amount of solar radiation received per unit area by a surface perpendicular (normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky

Electrical grid – an integrated system of electricity distribution, usually covering a large area.

Funding Opportunity Announcements (FOAs) –refers to a notice received for federal grant funding opportunities

Gigawatt (GW) – a unit of power equal to 1 000 000 000 Watts, 1 000 000 kilowatts, or 1 000 megawatts.

Heliostat - a multi-component apparatus used to compensate for the sun's apparent motion in the sky which includes a reflective surface, usually a planar mirror, with a mechanically controlled range of motion used to reflect sunlight in a constant direction toward a predetermined target.

Heat transfer fluid (HTF) – in high temperature systems a fluid agent (gas, liquid or emulsion) used to cool or transfer heat from one region or area to another

Kilowatt (kW) – a standard unit of electrical power equal to 1000 watts, or to the energy consumption at a rate of 1 000 joules per second.

Kilowatt-hour (kWh) – 1 000 watts acting over a period of one hour. The kWh is a unit of energy. One kWh=3 600 kJ.

Levelised Cost of Electricity (LCOE) – frequently used in reference to investment into electricity generation, it is the minimum price of electricity at which a technology generates enough revenue to pay all of the generation medium's costs, including sunk capital expenditure, and provide an investment return

Megawatt (MW) – 1,000 kilowatts or 1,000,000 watts; standard measure of electric power plant generating capacity.

Overall annual efficiency – Efficiency of conversion of solar energy to net electrical energy output over a year

PCM – Phase-change material is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa. Also referred to as latent heat storage (LHS) units

Photon – a particle of light that acts as an individual unit of energy.

Poly-generation – generation of more than one useful energy product

Receiver – or solar receiver is a type of furnace, either external or cavity, designed to absorb the energy being reflected from a heliostat field and transfer it into a heat transfer fluid where the furnace is placed at a predetermined point to intercept incoming reflected radiation most efficiently.

Solar energy – electromagnetic energy transmitted from the sun (solar radiation). The amount of solar energy that reaches the earth is equal to one billionth of total energy generated, or the equivalent of about 420 trillion kilowatt-hours.

Solar thermal electric systems – conversion technologies that convert solar energy to electricity by heating a working fluid to power a turbine that drives a generator. Examples of these systems include central receiver systems, parabolic dishes, parabolic troughs and linear Fresnels.

Strategic Research Initiative (SRI) – a term used by the Australian Solar Institute and refers long-term, strategic and collaborative national research programs to underpin the researcher capacity required to deliver ‘over the horizon’ technologies not yet commercially viable

Supercritical CO_2 (sCO_2) – carbon dioxide operating above its critical point such that it behave as a fluid in a single phase that has some gas-like and other liquid-like properties

System Advisor Model (SAM) - a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry, developed by the USA National Renewable Energy Laboratory

USA Solar Energy Collaboration (USASEC) – used by the Australian Solar Institute and refers to the United States-Australia Solar Energy Collaboration as a funding mechanism to support collaborative research between the United States (US) and Australia that aims to fast-track cost reductions in capturing solar energy

Watt – the rate of energy transfer equivalent to one ampere under an electrical pressure of one volt. One watt equals 1/746 horsepower, or one joule per second. It is the product of voltage and current (amperage).

FOR FURTHER INFORMATION

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