



Solar Air Turbine Project

Final report: project results

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Contact name: Dr Jin-Soo Kim

Title: Principal Research Scientist, CSIRO Energy Transformed Flagship

Email: jin-soo.kim@csiro.au **Phone:** +61 2 4960 6000

Website: www.csiro.au





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Executive Summary

This project involved CSIRO and Mitsubishi Heavy Industries (MHI) further developing and testing the components required for building commercial solar air turbine systems. Comprehensive studies on receiver performance and system modelling were also conducted.



CSIRO Solar Thermal Tower, Newcastle, Australia

Project Overview

Project summary

The Solar Air Turbine project used an air Brayton Cycle for electricity generation. The technology does not require water for cooling, could be easily hybridised by gas co-firing, and improves the efficiency of small to medium-scale Concentrated Solar Power (CSP) systems to increase the viability of the technology. These unique advantages are expected to differentiate the technology from existing commercial CSP systems.

To commercialise the solar air turbine technology, low-cost and high-precision solar field technology and scalable high-temperature air receivers are required. Sound understanding of cavity receiver performance and reliable modelling capability are additional requirements. In the long term, investigation of coupling high-temperature thermal storage options is beneficial.

Project scope

The project covered the following six activities to target viable, low cost commercial solar air turbine systems:

1. Engineering of high precision, low cost and market-ready heliostat targeting a cost lower than \$150/m².
2. Design, manufacturing and test of high temperature tubular air receiver and demonstration of turbine power generation.
3. Development and test of a prototype next generation receiver.
4. Cavity receiver performance evaluation.
5. Demonstrating dispatchable power by co-fired power generation and an experimental test of a high temperature thermal storage system.
6. Design of commercial and pilot-scale solar air turbine systems.

The Solar Air Turbine project set out to achieve:

- proof of concept low-cost and high-efficiency heliostat systems;
- successful demonstration of high-temperature receivers and turbine-integrated power generation;
- a new molten metal storage system;
- competitive modelling capabilities for receiver performance and system economics; and
- initial designs of pilot and commercial scale solar air turbine systems along with performance and economic projections.

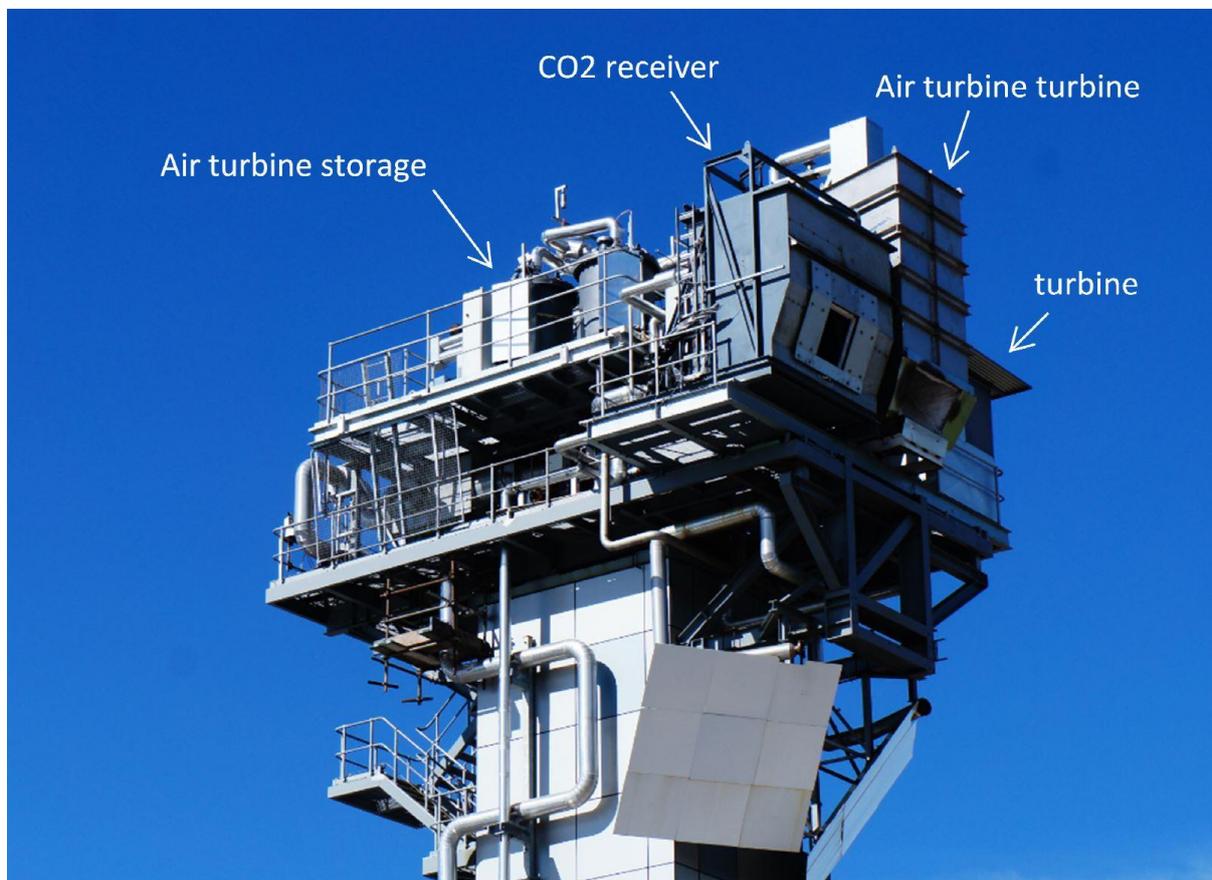
Outcomes

High-precision optics and heliostat control is required for the successful operation of a high temperature cavity receiver and has been successfully demonstrated. The costing study for low cost heliostat for mass production found a very competitive heliostat cost as low as \$100/m² could be achieved. Fabrication and testing of a 150 metre focal length heliostat has been also completed for larger scale solar fields.

The project developed scalable high temperature air receivers. This is the most important component for commercialisation of solar air turbine systems. Testing of a 600 kWth tubular cavity receiver achieved 850°C receiver outlet air temperature which is one of the world's highest. A new receiver adapting a novel beam redirection concept was also designed and successfully tested at a smaller scale. Also, by integrating a turbine to the new receiver, solar power generation was demonstrated. To date, only few research groups have experimentally demonstrated power generation using a similar technology.

From receiver performance studies, multiple scientific outcomes were achieved. These include comprehensive computational fluid dynamics (CFD) analysis of cavity receiver heat loss, development of a simplified model for an easy and reliable estimation of cavity receiver heat loss, and investigation on time-dependent cavity receiver cooling behaviour.

Using a shutter on the cavity receiver inlet to conserve heat between daily cycles has been investigated both theoretically and experimentally. The results showed reduced heat loss as a key benefit.



CSIRO Installed Storage System, Newcastle, Australia

A very challenging high-temperature thermal storage concept using liquid metal (LBE) as a storage material was experimentally investigated. For the activity, new design concepts like furnace-embedded, internally-lined storage vessel and pumping by pressurised gas were implemented. Corrosion tests of different metals dipped in very high temperature LBE were also carried out to identify preferable metals for heat exchanger construction and containment vessels.

Modelling capability for system performance and economics was developed and used for comparative investigation of different system configurations and performance/cost projections of proposed pilot and commercial solar air turbine systems.

Preferred design of pilot 2.5 megawatt equivalent (MWe) and commercial 10 MWe solar air turbine systems were proposed along with performance and cost projection results. Estimated LCOE of proposed systems are 55 cent/kWh for 2.5MWe system and 24 cent/kWh for 10 MWe system, respectively. In terms of system configuration, the proposed systems employed a hybridisation option but did not consider thermal storage due to its immaturity. However, it was found that in order to make very low cost (<14 cent/kWh) power generation achievable, thermal storage needs to be integrated along with further capital cost reduction of plant and equipment.

Transferability

The project has significantly advanced the concept of the Solar Brayton cycle and pointed the way to further areas of research to reduce costs further and to increase the efficiency of the system, especially in conjunction with hybridisation and high temperature thermal storage.

The project included multiple independent activities which were carried out in parallel. This enabled the concepts to be evaluated to various degrees of technical proof. This "fast development" style project enabled demonstrations of concepts and trials of advanced concepts.

Further gains in effectiveness could be achieved through allowing for extended operation of the designs.

Low-cost and high precision heliostat can be applicable for all different tower type CSP systems to make them more economically efficient.

Scalable cavity receiver concepts will enable the design of large-scale high temperature solar receivers to be feasible. This technology will be necessary and applicable not only for solar air turbine systems but also all other high temperature systems which are beyond the temperature range of current CSP systems.

Extensive experiences and know-how developed or enhanced by the project can be directly used for designing, building, running and evaluating other new CSP systems.

Successful deployment of solar air turbine technology will create a new market of small to medium scale CSP systems especially beneficial to remote areas.

Conclusion and next steps

Construction of a reasonably-priced (not significantly more expensive than the current commercial CSP systems) 10-MWe scale solar air turbine systems seems to be viable in the near term.

The recommended system does not include thermal storage but hybridisation with gas of a high-efficient turbine is an essential part.

Deployment of solar air turbine systems in Australia appears feasible based on:

1. low risk of relatively small CSP systems,
2. no need for cooling water, and
3. easy hybridisation with gas not only for a better efficiency but also for a consistent power generation.

Experience with a 3 to 5 MWe scale pilot system should precede the commercial introduction of the plant and provide longer term durability test of heliostats and the developing or sourcing of a solarised turbine.

Other resources

<http://www.csiro.au/Outcomes/Energy/Renewables-and-Smart-Systems/Solar-Energy-Centre.aspx>

<http://csirosolarblog.com/>