Designing the standard small-scale particle-based CST system for remote or edge of grid applications

Mehdi Aghaei Meybodi, Andrew Beath, and Daniel Potter

CSIRO Energy, Newcastle Energy Centre, 10 Murray Dwyer Circuit, Mayfield West, NSW 2304, Australia
E-mail: mehdi.aghaeimeybodi@csiro.au

Mining and minerals industry operations are significant contributors to both Australian export earnings and carbon emissions. Increasingly, the emissions from production of the exported materials are being considered by international customers and this is resulting on pressure to introduce new technologies to decarbonise the Australian industries. A significant portion of the operations in this sector occur in remote regions throughout WA, NT, SA, QLD and NSW that have high solar availability. As the industries often operate 24/7, it appears that high-capacity factor technologies such as solar thermal with integrated storage are likely to provide an effective approach to achieving large carbon reductions compared to the more variable renewables, but a package of technologies at a suitable scale for the sites needs to be developed.

Conventional central receiver systems have proved promising for large scale CST applications, such as grid connected locations, but in remote and edge of grid areas where smaller systems are required it is less likely that the molten salt systems will be economically or technically attractive. In this current study a novel CST system which utilizes particle technology is analysed as an alternative approach that may be more viable at smaller scales. The advantages of particle systems include low corrosion, toxicity, and explosion risk, that suit maintenance using conventional equipment and capabilities found in general industries. Also, the system can operate over a wide range of temperatures with no risk of phase-change and containment requires simple insulated tanks without special materials. The present work seeks to design standard small-scale particle-based CST systems to be used in techno-economic assessments at different Australian locations.

Methodology

A dataset from Geoscience Australia[1] which provides data on the Australian power generators along with mines and mineral processing sites has been used to locate the power generators. The dataset also includes other details such as fuel types and capacities. However, it was last updated in 2017 and therefore misses more recent installations. To address this, the Australian subset of the Global Power Plant Database[2] has also been used and Figure 1 depicts the combined set of Australian power generators and their fuel type. Nationwide House Energy Rating Scheme[3] (NatHERS) has divided Australia into different climate zones and provided Typical Meteorological Year (TMY) weather files for a representative site in each zone. The NatHERS 2016 data files have been used to provide typical weather data in the region of each generator site. Four classifications of site have been specified based on the solar availability, namely 1) very high solar intensity region (DNI≥2500 kWh/m^2/y), 2) high solar intensity region (2300 kWh/m^2/y ≤ DNI <2500 kWh/m^2/y), 3) moderate solar intensity region (2000 kWh/m^2/y ≤ DNI <2300 kWh/m^2/y), and 4) low solar intensity region (2000 kWh/m^2/y > DNI). Table 1 summarises the details of the Australian power generators. Six sites have been selected for the detailed techno-economic analysis based on the size and type of the existing power generators in their proximity: Broome and Kalgoorlie in

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[1] www.ga.gov.au

[2] https://datasets.wri.org/dataset/globalpowerplantdatabase

[3] https://www.nathers.gov.au/nathers-accredited-software/nathers-climate-zones-and-weather-files

the high solar intensity and Mt Isa, Meekatharra, Alice Springs, and Newman in the very high solar intensity regions.

The studied CST system consists of a heliostat field with a tower mounted falling particle receiver, particle storage, a staged particle heat exchanger, and a particle lift to transport particles to the top of the tower. Customised software compiled from CSIRO's Heliosim codebase (Potter et al., 2018) is used to optimise and simulate the solar collection subsystems (i.e., solar field, particle receiver and tower). Component costs are derived from a range of CSIRO and international studies on similar particle technologies with a sCO2 Brayton cycle selected as the power block for the system. Specifically, the sCO2 power cycle model incorporated in SAM (version 2018.11.11) has been utilised to optimise and model the sCO2 cycle's performance. The maximum particle temperature has been limited to 700° C to avoid cost escalations due to the special materials needed for higher temperatures. A combination of power cycle optimisations and literature review has led to selection of the partial cooling cycle with the design efficiency of 48% for this particle-based CST system. The minimum particle temperature is considered to be 470° C based on the optimised value by SAM.

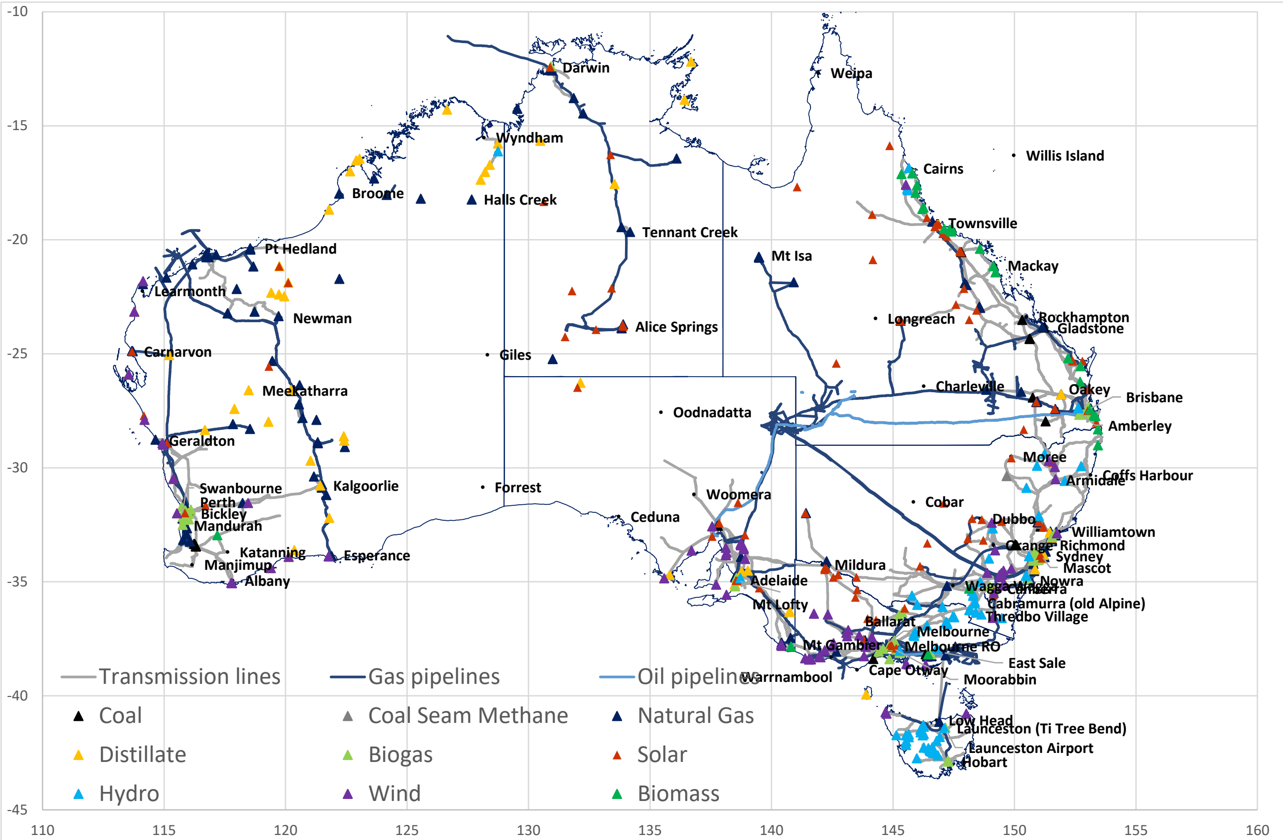

Figure 1. Power generators across Australia

Table 1 Power generators in different solar availability regions

Solar region	Number of sites	Minimum capacity (MWe)	Maximum capacity (MWe)	Average capacity (MWe)	Total capacity (MWe)
Very high solar intensity	102	0.01	530	53.0	5403.2
High solar intensity	56	0.02	856	141.2	7904.8
Moderate solar intensity	186	0.11	2640	161.0	29937.1
Low solar intensity	221	0.14	2880	131.7	29102.1

Particle-based systems utilise cavity receivers to minimise particle egress and convective heat loss, which necessitates increased accuracy in the heliostat field design and control. In the present work, CSIRO's patented truncated cone falling particle receiver concept is considered (Kim et al, 2020). Three receiver capacities are considered: 50, 150, and 450 MWt. A 50 MWt plant is deemed to be an appropriate size for demonstration purposes, while 450 MWt appears to be sufficiently large for most remote and edge of grid power supply operations.

Results

Table 2 provides the optimum size and storage capacity of the sCO2-based CST system for the three studied receiver sizes at the six considered sites. As evident, utilising a 450 MWt receiver results in the most cost competitive options. For all the sites 14 hours proves to be the optimum storage size. The average turbine size is 63 MWe gross (nearly 56.8 MWe net). Figure 2 shows the variation of LCOE with storage capacity and turbine size in Meekatharra. As evident from the figure at 14 hours of storage differences in LCOE values are negligible for the turbine sizes within the 60-70 MWe range and therefore the available turbine size in the market could be selected. This is not unique to Meekatharra and holds for all the studied sites.

Table 2 Summary of results

	50 MWt			**150 MWt**			**450 MWt**		
Site	Gross turbine size (MW)	Storage capacity (h)	LCOE (c/kWh)	Gross turbine size (MW)	Storage capacity (h)	LCOE (c/kWh)	Gross turbine size (MW)	Storage capacity (h)	LCOE (c/kWh)
Broome	6	16	25.8	20	14	20.8	61	14	18.6
Kalgoorlie	7	14	28.5	21	14	23.2	64	14	20.7
Mt Isa	6	16	25.7	20	14	20.8	62	14	18.6
Meekatharra	7	14	25.7	20	14	20.8	62	14	18.6
Alice Springs	7	16	24.3	22	14	19.7	66	14	17.6
Newman	7	14	26.1	21	14	21.1	64	14	18.8

References

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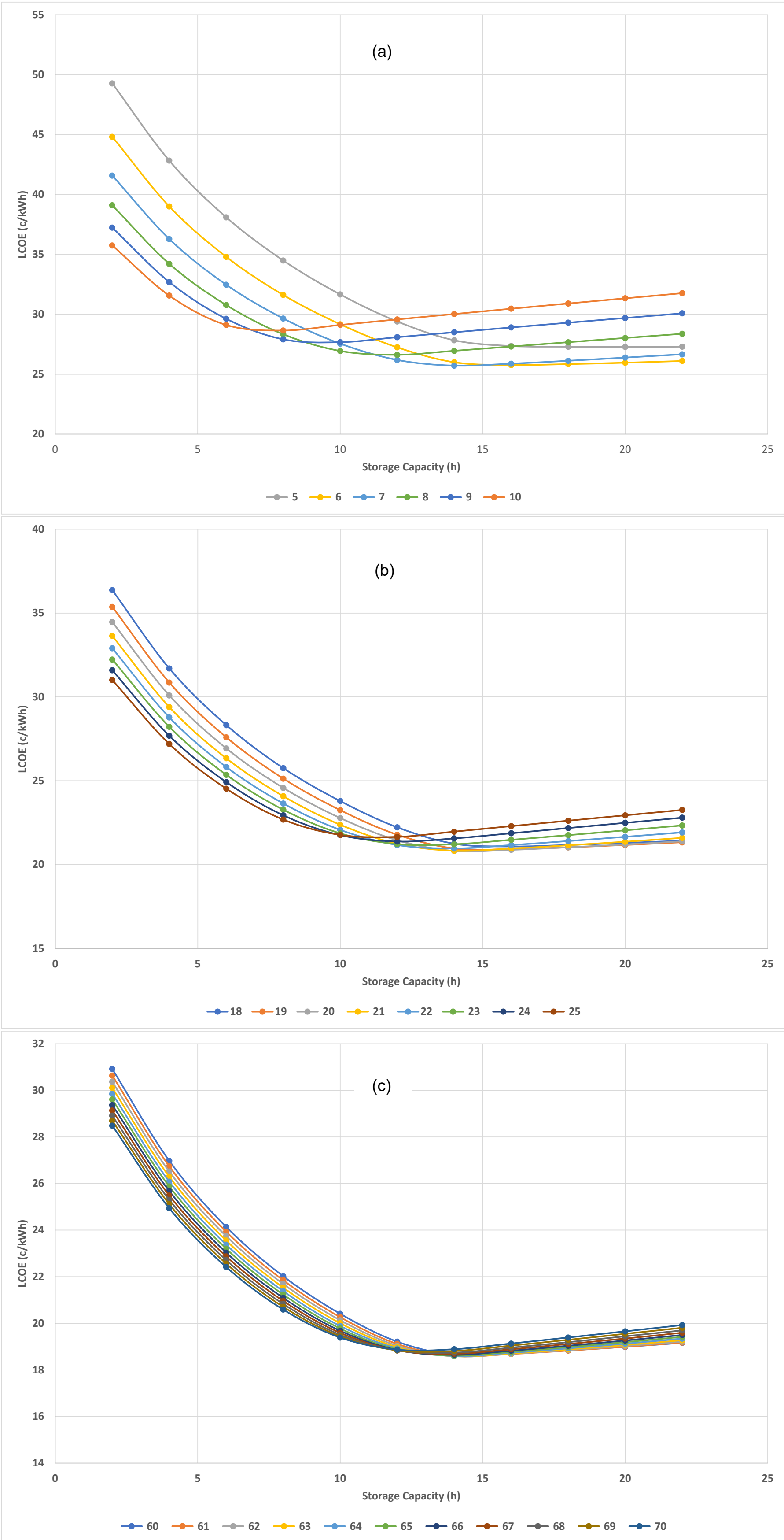

Figure 2. Variation of LCOE versus storage capacity for different turbine sizes for a) 50 MWt, b) 150 MWt, and c) 450 MWt receivers in Meekatharra