Australian Government
Australian Renewable Energy Agency

ARENA

SYNTHESIS OF RESPONSES TO ARENA'S 2017 REQUEST FOR INFORMATION (RFI) ON CST PROJECTS

Public Summary

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About this report

Prepared by ITP for the Australian Renewable Energy Agency (ARENA).

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The ITP Energised Group, formed in 1981, is a specialist renewable energy, energy efficiency and carbon markets group of companies. The group has member companies and offices and projects throughout the world.

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LIST OF ABBREVIATIONS

ARENA	Australian Renewable Energy Agency
CPC	Compound Parabolic Concentrator
CSP	Concentrating Solar Power
CST	Concentrating Solar Thermal
DNI	Direct Normal Irradiation
EOI	Expression of Interest
EPC	Engineer, Procure and Contract
GW	Gigawatt, unit of power = 1,000 MW, subscript e for electric, th for thermal
ITP	ITP Energised Group
LCOE	Levelised Cost Of Energy
LFR	Linear Fresnel Reflector
LGC	Large-scale Generation Certificate
MW	Megawatt, unit of power = 1,000 kW, subscript e for electric, th for thermal
MWh	Megawatt hour, unit of energy (1 MW generated/used for 1 hour)
O&M	Operations and Maintenance
OE	Owners' Engineer
OEM	Original Equipment Manufacturer
PPA	Power Purchase Agreement
PTC	Parabolic Trough Collector
PV	Photovoltaic
QA/QC	Quality Assurance / Quality Control
RET	Renewable Energy Target
RFI	Request for Information
VRE	Variable Renewable Energy

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EXECUTIVE SUMMARY

Concentrating Solar Thermal (CST) power systems use mirrored concentrators to provide heat for power generation using steam turbines and synchronous generators. Most recent systems incorporate 3 to 15 hours of thermal energy storage. At the beginning of 2017, there was $5GW_e$ of generating capacity in around 100 utility scale CST power plants around the world operating on a commercial basis.

CST systems are also used in industrial sites for direct supply of process heat to reduce reliance on gas and diesel boilers.

The Australian Renewable Energy Agency (ARENA) issued a Request for Information (RFI)[1] to test the market for CST projects on 25 May 2017. The RFI process was designed to examine the potential for a possible program supporting the deployment of CST systems in Australia. The RFI process called for responses by 31 July 2017.

The result was:

- 31 responses building on experience from every significant CST system globally.
- Directly expressed and implied interest in involvement in CST deployment in Australia.
- Universally positive views on the future of CST.
- All responses referred to the key advantage of cost effective, integrated thermal energy storage and the characteristics of dispatchable generation via synchronous generators.
- A clear indication that a large scale competitive CST process in Australia would be well subscribed

Respondents included large companies who have been instrumental in the global CST industry over the past decade, plus small companies developing new technology approaches, as well as some key industry associations and others. In addition to Australian based companies, responses were received from Spain, USA, Germany, Italy, India and Chile. While a few responses are brief, most include an impressive level of detail and represent a significant effort, indicative of the interest in Australia as a future market.

Overall, the combined global experience in CST is well represented with the total sector experience of respondents in excess of the total existing installed capacity, reflecting that respondents have in many cases been involved in the same projects in different roles.

[1] https://arena.gov.au/news/arena-to-test-market-for-concentrated-solar-thermal-projects/

Responses are universally positive about the future of CST. All respondents referred to the key advantage of cost effective, integrated thermal energy storage in various levels of detail. This included characteristics of dispatchable and flexible generation coupled to the benefits of synchronous generation with inherent inertia. The ability to configure plants for dispatch strategies ranging between peaking to continuous output is widely discussed with many specific examples provided.

The cost discovery aspect of the RFI has been limited as might be expected. Major companies will be circumspect about their competitive position until a specific competitive process that they wish to succeed in is offered. The most ambitious cost estimates that were provided came from the smaller technology development companies who do not yet have a track record of deployment but clearly wish to sell the potential of their approaches. Experienced companies and industry associations offered commentary based on recent international procurements and publicly available reports such as IRENA 2016[2]. All were confident that cost reductions have been occurring and will continue. A number of experienced players provided detailed discussions of the various areas from which they are confident cost reductions would be contributed even though they did put down their own estimate on current LCOE.

It is universally acknowledged that CST LCOE is higher than PV at the present time, but respondents argue that the extra values offered justify such extra cost. Significantly this position was also offered by large international players who have successful track records in large scale PV as well as CST. The complementary nature of the two was also noted. Many submissions note that one of the continuing challenges to CST deployment is the general lack of specific reward in Renewable Energy support mechanisms (such as Australia's RET) for the extra desirable benefits that CST with storage brings.

The RFI process made a general reference to the context of the specific support of $110m equity investment that is on offer from the Australian Government for a Port Augusta project. A minority of responses outline a specific project specification for which they could seek ARENA, a further subset of these mention specific sites such as Port Augusta.

It is clear that any large scale competitive process to advance CST in Australia would be well subscribed by a critical mass of experienced players as well as smaller players seeking to progress towards commercialisation.

2 IRENA 2016, THE POWER TO CHANGE: SOLAR AND WIND COST REDUCTION POTENTIAL TO 2025. International Renewable Energy Agency.

1. INTRODUCTION

The Australian Renewable Energy Agency (ARENA) issued a Request for Information (RFI) to seek information on the market for Concentrated Solar Thermal (CST) projects on 25 May 2017. This information was sought to inform the design options for any potential support program targeting deployment of CST systems in Australia.

It was noted that *"Interested parties are expected to include (but are not limited to) project proponents, debt and equity investors, original equipment manufacturers, off-takers and government entities."*

Responses were due before 5pm on 31 July 2017. All CST types and projects sizes were of interest. This consideration of CST follows on from ARENA's recent successful large-scale solar photovoltaic generation competitive round. It also closely follows one of ARENA's investment priorities, "Delivering Secure and Reliable Electricity."

1.1. CST Background

Concentrating Solar Thermal (CST) systems use systems of mirrors to focus the direct beam solar radiation to smaller areas and allow high temperatures of many hundreds of degrees to be reached. They are suitable for operation of large thermal power stations as well as advanced thermochemical processes and industrial process heat.

There are four main CST technologies – linear Fresnel, parabolic trough, heliostat with tower and paraboloidal dish as summarised in Table 1. While trough plants have the longest track record of operation and account for the bulk of systems deployed, tower plants are emerging as a more favoured option for power generation, due to the higher temperatures and efficiencies as well as more cost-effective energy storage that has been achieved. Linear Fresnel and dishes have their own advantages and are also being actively pursued.

CST power systems almost exclusively use steam turbines to generate electricity in a similar manner to fossil fuel fired power stations. They provide synchronous generation with inherent inertia. There are advanced power cycles with higher efficiencies that are the subject of research and development activities and may come into play in the future.

Table 1. Summary of CST types.

Technology		Description
Parabolic trough **100 - 450ºC**		A tubular receiver is fixed to the focal line of the array of parabolic mirrors, which track the sun along one axis throughout the day. Trough systems can heat a heat transfer fluid such as synthetic oil, or generate steam directly for process heat or power generation.
Linear Fresnel **100- 450ºC**		Removing the need for a moving receiver and flexible couplings, the Linear Fresnel system is similar to a trough concentrator in that it provides heat over the same temperature range. Long, semi flat mirror strips in parallel rows track the sun independently, to focus direct beam radiation on a linear focus that is fixed on a non-moving frame.
Heliostats and tower **300 - 1500ºC**		For higher temperatures, the heliostat field plus tower arrangement is available. Many Individual mirrors on double-axis tracking devices are all simultaneously moved to reflect sunlight to a single receiver on a tower, which reach temperatures of around 600°C for current commercial systems, but can reach much higher temperatures in excess of 1500°C.
Dish **300 – 2000ºC**		A mirrored paraboloidal dish system can also offer high temperatures and with a higher efficiency than tower systems. However, this approach is less commercially mature than tower systems.

CST plants are complex integrated systems made up of a series of subsystems. This is illustrated for the particular case of a molten salt tower plant in Figure 1.

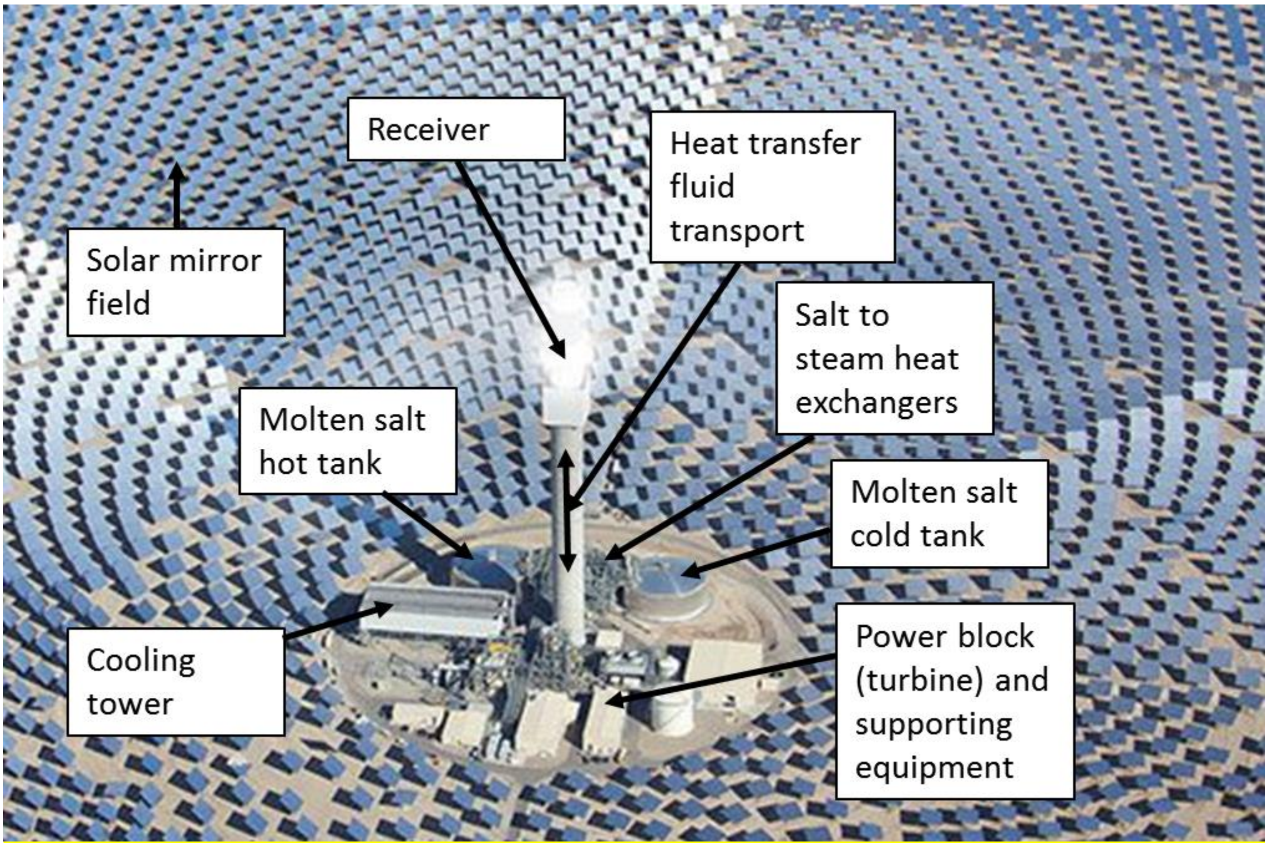

Figure 1: Subsystems in a molten salt tower plant.

Key subsystems are:

- The mirror field that gathers solar radiation and directs it to a focal point by tracking the sun during the day.
- The receiver that intercepts the radiation and converts it to high temperatures.
- The heat transfer fluid system that takes heat from the receiver and transports it to storage and/ or power block.
- The thermal storage subsystem that is typically based on two tanks of liquid salt but can use other processes also.
- The power block and associated equipment that is typically based on a steam turbine.

CST power plants are attracting increasing interest due to their ability to store large amounts of energy and provide dispatchable electricity supply. The current industry standard approach is to use a mix of molten nitrate and potassium salts as a heat storage medium that is moved between a 'cold' tank at around 250ºC to a 'hot' tank at 400ºC or 600ºC depending on the concentrator type.

Globally, after an initial start in the late 1980s followed by some years of hiatus, CST has been growing strongly since around 2006. However, CST's deployed generation capacity is only about 2% of the global PV industry but with a trajectory that matches that of PV's growth about a decade earlier.

By the beginning of 2017, global installed CST power generation capacity had increased to around 5 GW_e as shown in Figure 2. Spain and the US are where most development has occurred but in the last few years, activities in other regions started growing, particularly in China, Chile, the Middle East, North Africa and South Africa. This 5 GW_e is made up of around a hundred individual power plants mostly of 50 MW_e or more in capacity. They all continue to operate on a commercial basis according to the various offtake arrangements in the countries concerned.

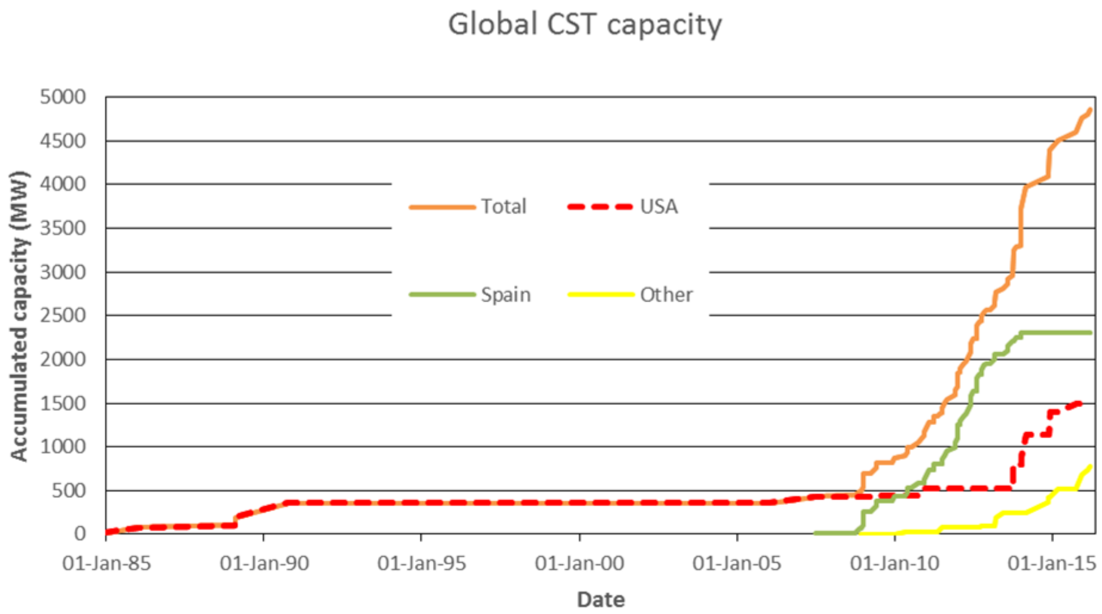

Figure 2: CST Installed capacity growth, (ITP).

On a simple LCOE basis, CST electricity is more expensive than wind or photovoltaics. However, in recent years, the majority of CST power systems have incorporated integrated thermal energy storage systems of between 3 to 15 hours of nameplate generation. This ability to provide firm, dispatchable and flexible generation inherently is now widely recognised as the main competitive advantage of the technology.

Mainly due to poor program design, Australia has made limited progress in CST deployment with previous support attempting to facilitate solar boost projects for existing coal-fired power stations. Sundrop Farm in SA is the largest tower system (39 MW_{th} and 2 MW_e) in Australia which is mainly used for heat. CSIRO also has a small research tower system in Newcastle used to research natural gas reforming. Other Australian companies are also developing and deploying tower, trough and dish systems.

1.2. The Information Requested

The RFI asked respondents to consider:

- “the nature of their interest in CST (for example as an investor, developer, technology provider, off-taker, regulator their experience with CST)
- their view of CST’s potential value proposition relative to other renewable generation technologies
- any preferences with respect to firm generation profile and potential value uplift for that purpose
- regulatory, commercial, market or technical barriers and opportunities facing CST
- environmental considerations in CST deployment
- their views of the key risks in CST projects and how they might be best mitigated
- preferred energy and renewable energy certificate offtake arrangements
- factors differentiating such projects from other technology solutions, and
- any other information the respondent feels may be relevant to the ARENA and CEFC’s consideration as to how best to support the deployment of CST.”

Where respondents are considering potential roles as CST project developers or contractors respondents were invited to outline their views of:

- “the optimal maximum and minimum CST project sizing (rated capacity, storage hours), location and dispatch profile
- the expected capital and operating costs of deploying the optimal project
- expected areas of future capital and operating cost reduction (local and international replication) by, for example:
  - anticipated technology improvements
  - anticipated capital cost reductions
  - potential to develop the local supply chain
  - future labour savings and risk margin savings in delivery
  - expected local content and the potential for local industry development
  - expected annual energy output
  - likely construction and commissioning timeframes, and
  - potential grid impacts.”

2. ANALYSIS AGAINST THE RFI QUESTIONS

The section headings below are based on a paraphrased version of the questions in the ARENA RFI. The combined views of respondents are synthesised against each topic.

2.1. The nature of respondent interest in CST

The type of organisation and level of CST experience of the 31 respondents are listed in Table 1. Respondents include large organisations who have been instrumental in the global CST industry over the past decade, plus small companies developing new technology approaches, in addition to some key industry associations and others. In addition to Australian based companies, responses have come from Spain, USA, Germany, Italy, India and Chile. While a few responses are brief, most include an impressive level of detail and represent a significant effort, indicative of the interest in Australia as a future market.

Overall, the combined global experience in CST is well represented, with the total sector experience of respondents in excess of the total existing installed capacity, reflecting that respondents have in many case been involved in the same projects in different roles.

Several relevant industry associations responded. It was apparent that their member companies are experienced in all roles with combined capabilities matched to all aspects of the CST value chain. Although many of these companies have not responded directly to the RFI, it is apparent that the organisations speak for them and by implication they are potentially interested in Australian opportunities.

Table 1. Submissions received in order of level of previous experience in the role.

No	Industry role	Country of origin	Experience in role (MWe approx)
1	Engineering services	Australia	7,700
2	Industry association	Spain	4,000
3	Industry association	Europe	3,500
4	Technology provider, EPC	Spain	2,060
5	Industry association	Germany	2,000
6	Component supplier	Chile	1,000
7	Engineering services	Spain	1,000
8	Technology provider	Spain	1,000
9	EPC, Project Developer	Spain	700
10	OEM, EPC,	Spain	500
11	Technology provider, Project developer	USA	500
12	Technology provider	Belgium	150
13	Technology provider, Project developer	USA	100
14	Consultant	Australia	90
15	Project Developer	Abu Dhabi	30
16	OEM, EPC,	Germany	30
17	Project developer	India	10
18	Developer, Technology supplier	Australia	3
19	Technology developer	Australia	1
20	Technology developer, component supplier	Australia	0.1
21	Technology developer	Italy	0.1
22	Technology developer	USA	0.1
23	Industry association	Australia	0
24	Project Developer	Australia	0
25	Research	Australia	0
26	Technology developer	Australia	0
27	Technology developer	Australia	0
28	Technology developer	USA	0
29	Technology developer	USA	0
30	Industry association	Australia	..
31	Government	Australia	..

2.2. CST's potential value proposition relative to other renewable generation technologies

With the exception of one small company advocating concentrating PV, all responses are universally positive about the future of CST. All referred, in various levels of detail, to the key advantage of cost-effective, integrated thermal energy storage. This storage offers characteristics of dispatchable and flexible generation coupled to the benefits of synchronous generation with inherent inertia that follows from the use of steam turbo generator based power blocks. The ability to configure plants for dispatch strategies ranging between peaking to continuous output is widely discussed with many specific examples provided.

There is an overall view that globally, nuclear and fossil generation plants are becoming progressively harder to finance due to the combination of cost, carbon risk and pollution / safety issues. Thus CST advocates predict most future electricity generating capacity constructed globally will be renewable. It thus becomes essential to include dispatchable renewables such as CST with storage in that mix. The balancing of variable renewable energy (VRE) in Australia has largely been done by gas plants to date, but this is the obvious role for CST with storage. Illustrations with real data on how the portfolio of Spanish CST plants produces output that tracks Spanish electricity demand consistently is pertinent to this case.

A number of submissions categorise and list the sources of value that is offered, each expressing the concepts slightly differently. These categorisations can be paraphrased as:

- **Dispatchable / flexible generation:** thermal storage allows a CST system to provide energy generation to match the highest-value / demand times on the grid.
- **Firm Capacity:** known reserves of energy allow generation capacity to be reliably known in advance of its provision. If desired a portion of the energy can be held as a strategic reserve. In this way complete replacement of traditional coal-fired generation is possible.
- **Ancillary Services:** The dispatchability afforded by molten salt storage allows a CST power plant to deliver traditional ancillary services to the grid including frequency regulation, spinning reserve, non-spinning reserve, load following services, and black start capability. Each of these is important to the reliable functioning of the grid, particularly as penetrations of VRE increase.
- **Intrinsic Stability:** A steam turbine coupled to a synchronous alternator provides a built in source of stored kinetic energy in the heavy spinning machinery that serves to dampen sudden unexpected changes of frequency without the need for any form of electronic control system. Some level of system inertia of this kind is considered essential and CST power systems provide it in the same way that coal or gas generators have done traditionally.
- **Network Support:** CST power systems are best built in a distributed fashion in high solar areas such as inland, fringe-of-grid locations. This combined with the ability to provide firm capacity allows them to reduce peak demand on network assets that are becoming constrained, thus avoiding the cost of potential network upgrades.

Other key points made on the value proposition include:

- There is no 'round trip' energy loss as with batteries for example, since storage is integrated. Insulated, molten salt tanks have very small standing losses.
- A present CST investment can also be seen as a 'hedge' against future VRE integration costs.
- Energy can be held back from the day before when a partly cloudy day is predicted.
- The dispatchability characteristics result in firm capacity that allows for major projects in fringe of grid / isolated grid situations where the CST power plant can be the major local source of capacity. This is the case for the large South African and Chile projects for example.
- With tower plants in particular, there is no progressive degradation over time of generation capacity that is seen with PV for example. Supporting this assertion, monitoring Spanish plants shows that year by year annual production is consistently maintained.
- The size of the power block, solar field and energy storage can be varied from plant to plant allowing plants to be configured to meet specific network or market needs.
- After a plant is built the operator can make decisions as to how it will operate to optimise return, this can evolve over time as market circumstances change.
- CST provides the opportunity to create a new Australian Industry.

Overall the view of respondents is that CST power characteristics offer significantly higher value at a slightly higher energy cost than VRE.

2.3. Preferences with respect to firm generation profile

On the whole, respondents do not express strong preferences for particular generation profiles. The central theme is that CST power system design involves an optimisation of power block, thermal storage and solar field sizes. Different generation profiles can be achieved through different combinations of the system design parameters. The system configuration adopted is based on economic optimisation driven by the nature of the market signals experienced.

Many respondents presented indicative daily profiles to illustrate the possible generation profiles that are achievable with CST/storage. An example is reproduced in Figure 3.

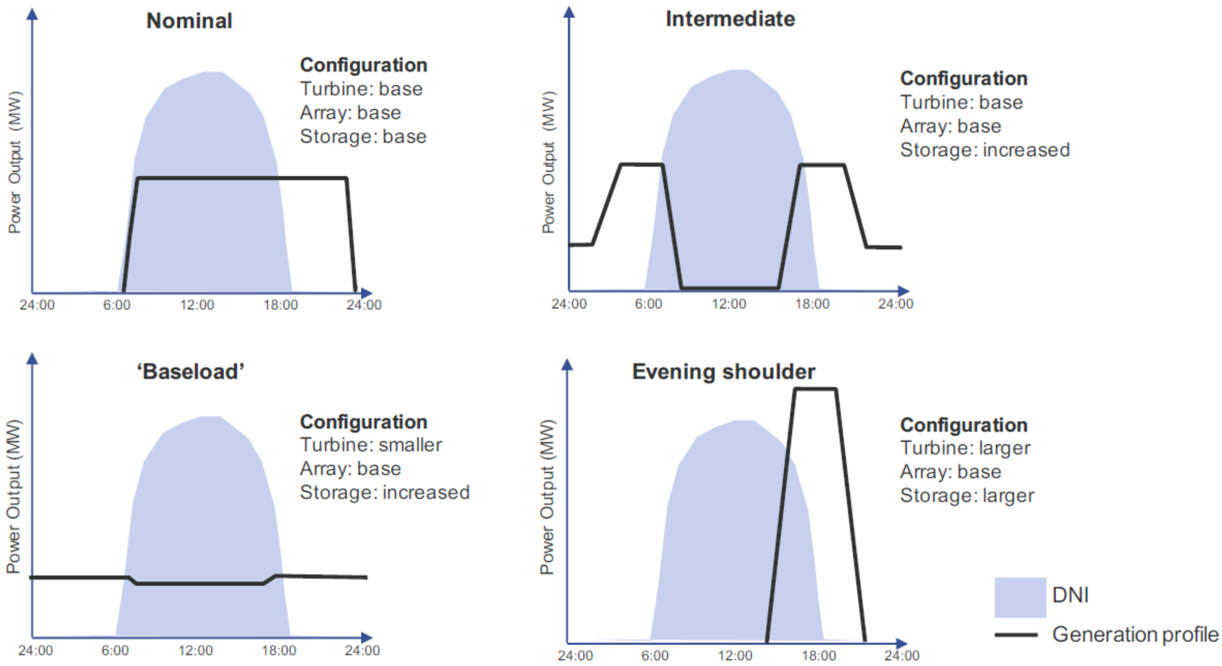

Figure 3. Alternative generation profiles (Vast Solar).

In this illustration, the nominal arrangement sees generation during sun hours but with sufficient energy storage and energy collection to extend firm generation through the evening. Adding extra storage allows for energy collection during the day with no generation, such that the generation can be reserved for morning and evening peaks (intermediate). Reducing the turbine size means that a smaller turbine can operate virtually continuously to supply 'baseload'. Conversely, keeping the larger storage and adding a larger turbine is needed to produce a peaking plant to generate in the late afternoon early evening.

It is the continuous output configuration that provides the lowest LCOEs. However, other approaches are expected to produce greater value in a supply and demand driven electricity market.

Any plant, once built, can be operated in a manner that attempts to achieve the best economic outcome based on continuous adaptation to forward predictions of solar radiation levels and demand or wholesale price. This could mean for example, holding energy in reserve for predicted coming cloudy days.

A few respondents advocated a technical solution with sufficient storage for continuous output behaviour. This was seen as particularly suitable for off-grid or fringe-of-grid applications. The general view for main-grid connection however, is that all signs point to the desirability of flexible operation rather than a continuous output generation profile.

Many respondents discussed the complimentary nature of PV and CST. This is based on the generally accepted view that during sun hours PV without storage offers a lower LCOE than CST. Thus, if the two technologies are optimised together, either behind the connection point or on a system wide basis, then the combination may offer the most cost-effective approach overall. Two scenarios for this are illustrated in Figure 4.

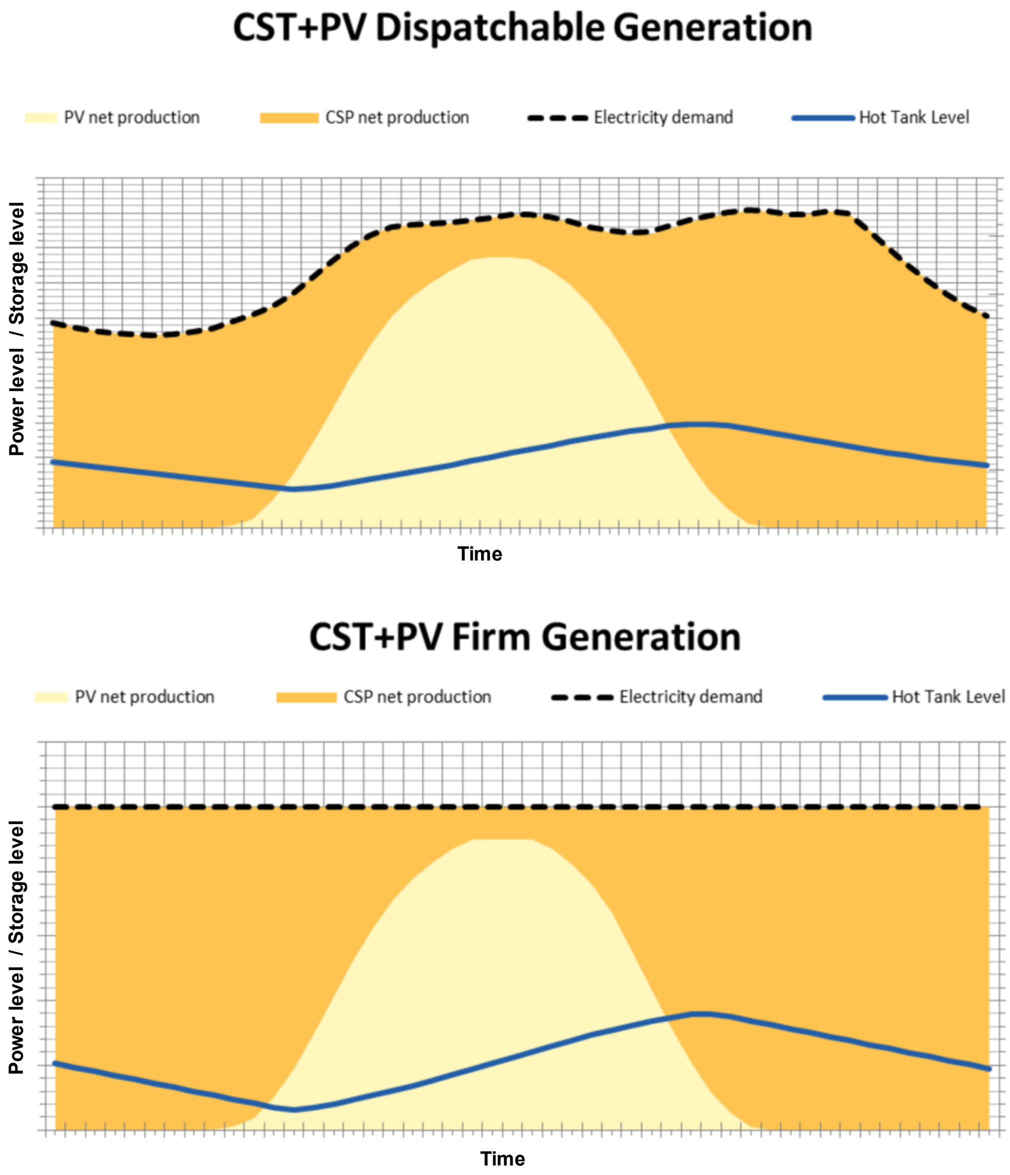

Figure 4. Alternative generation profiles (Cobra).

In a dispatchable combination, PV generation is sized for about 90% of peak midday load and the CST system operates in a flexible manner to otherwise meet varying demand. It continues to operate at least 10% during midday to provide the spinning reserve needed for overall firming. Such a scenario could apply to a particular (micro-grid or isolated mini-grid) region where one large system or a collection of PV and CST systems are providing virtually all generation. In the second scenario of a firming combination, the PV operation is the same, but the CST component is varied to provide an overall fixed and firm level of generation.

It should be noted however that steam turbines have reducing efficiency when run at part load, so overall energy generated is maximised when the CST system is operated at the power block nameplate capacity. Switching it off at other times may be more economically optimal, although there are energy and time penalties for restarts.

2.4. Regulatory, commercial, market or technical barriers and opportunities

The universally identified opportunity for CST is its ability to provide a lower cost solution to dispatchable and flexible solar electricity generation. This is at a time where increasing levels of variable renewable energy generation (wind and PV) are focussing attention on how best to maintain system reliability whilst continuing to lower emissions.

The lack of CST power deployment in Australia so far indicates that there are barriers. As already noted, it is widely recognised that CST LCOE is higher than PV or wind without storage. Thus, overall investment decisions that are largely driven by an LCOE comparison will not favour it.

Particular comments on barriers include:

- The challenges compared to wind or PV include the need for larger plants, higher technical complexity and larger construction periods. There is also a tension between seeking low technical risk and driving innovation for lower cost.
- A key challenge to CST in Australia is the regulatory / policy uncertainty. Risk premiums applied to costs and financing also represent an immediate challenge plus also a route to cost reduction.
- CST projects are significantly larger than minimum sized PV projects. This acts as a challenge in the early stages of adoption. Projects are also relatively complex and can require construction times of two years or more. The early stages of adoption also bring risk premiums to finance. The dispatchability benefits of CST power systems have not been properly rewarded in government renewable energy policies such as the RET.
- A large barrier to deployment has been the comparison of renewable technologies on a simple LCOE basis.
- A Renewable Energy Target (RET) mechanism that does not value storage combined with naïve comparisons of CST LCOE with wind and PV were discussed, in addition to the future policy uncertainty regarding the RET as well as energy and climate change policies.
- The electricity market does not adequately reward the benefits of CST power generation. These benefits include the synchronous generation from a steam turbine as well as the advantages from thermal energy storage providing known levels of reliability and security.

2.5. Environmental considerations

Generally speaking, respondents argue that the environmental issues associated with CST plants are straight forward and routinely dealt with. Particular observations include:

- Site choice is restricted to locations with good solar DNI, sufficient land available for large scale plants and water availability.

- Issues of heat transfer fluid oil (for troughs), tower visual impact and water usage are all important but routinely dealt with in projects around the world.
- Environmental issues are all manageable, but careful site choice and community engagement is essential. Visual aspects of towers noted.
- The desirability of moving away from the toxic and flammable heat transfer fluid oils used in trough plants.

Experienced CST global project developers listed the issues needing consideration in environmental impact assessments. These include:

- Cataloguing the environmental situation before construction of the project
- Classification of land according to zoning and land development plans
- Assessment of the local socio-economic environment
- Cultural, historic and archaeological values
- Fauna and vegetation found on the site and surroundings
- Hydro-geological situation and water quality
- Site noise measurement

Many of the world’s existing plants, particularly trough plants, have as part of construction a complete levelling of the site with removal of all vegetation. This would be a major impact in a sensitive area. However, there are approaches for heliostat fields in particular, that can see the solar field installed with minimal impact to vegetation and fauna.

Various respondents note the issue of bird deaths that has been raised at the large tower projects in the US. It is argued that following proper investigation and improved management of mirror fields, deaths are at a level commensurate with bird strike deaths on all man-made structures. Nonetheless, initial site assessment should obviously consider the potential impact on any sensitive species.

Many existing CST plants use evaporative cooling towers where low cost water is available. In such cases this is a major use of water as it is for most coal-fired power stations. However, as many respondents point out, there are now several CST plants that use air cooled condensers and this is likely to be a preferred approach in Australia.

2.6. Key risks and mitigation

The respondents with the largest track records of involvement in deployed projects have the most useful contributions to discussions of risks and mitigations. Some of the smaller companies in the area of new technology development tend to underplay and underestimate risks.

There are well known sources of risk, covering contracting, market, construction, transport, operation, geography and changes in solar resource over time. There is also a major tension between seeking low technical risk and driving innovation for lower cost.

Molten salt, central towers appear the most effective approach currently, but respondents also noted that there are relatively few tower examples in the world and the higher temperatures that are part of the efficiency advantage also bring more technical challenges.

A summary of a subset of some of the key risks and possible mitigations adapted from a well-qualified submission, with additions from others, is shown in Table 2.

Table 2. Some anticipated risks and mitigations.

Risk	Mitigation
Regulatory and market	
Change in the regulatory framework around market settings, carbon pricing renewable energy schemes	Carry out an analysis of the potential stability of the regulatory framework in the specific location. Sign PPA contracts if possible. Develop projects with relatively short return on investment periods.
Shifts in demand and market price as generation mix changes	Analyse financial performance over a range of scenarios. Build plants for flexible rather that continuous output generation. Adjust operating strategies as market evolves.
Project construction	
Disagreement between, engineering, procurement, vendors and constructors	Ensure alignment between the EPC/OE Engineering Team and critical suppliers in value chain to develop a reliable and realistic engineering framework, which facilitates timely and cost efficient construction.
Plant does not meet performance specification	Review, verify and validate critical equipment and processes, particularly: solar field, controls, receiver, heat exchanger/steam generators. Establish a Continuous Risk Management Process, assisting the Owner's team in defining priorities, implementing actions to reduce and avoid the risks as well as allocating resources. Purchase contracts including warranties for the main equipment, for all the operation modes and complete maintenance procedures.

Operation	
Lack of adequately experienced operators and local support staff	Comprehensive training from the EPC Contractor to the O&M team during the plant handover. Involve operations staff in part of construction and all of commissioning phases of the plant. Get input from experienced plant operators during training sessions, including the development of plant simulators to avoid damage to hardware. Include Thermal Power Plant operators in team.
Inadequate spares and maintenance	Give consideration to the remoteness of the site and the criticality of the various systems for defining spares and maintenance availability.
Technical	
Problems with solar field commissioning	Reliable commissioning procedures based on lessons learnt, and close QA/QC control during assembly. Early detection of issues in the Solar Field.
Problems with salt freezing	Engineering design according to lessons learnt and project requirements. Care to avoid cold spots causing freezing and hot spots causing accelerated corrosion.
Control integration and performance	Instrumentation and solar field control software optimised, based on commercial equipment optimised for CSP.
Premature deterioration of components	Accelerated aging tests. Use of experienced suppliers.
Failure of critical components	Design for back up and redundancy. Design for modularity and replace-ability.

2.7. Preferred offtake arrangements

Submissions do not overall have strong positions on the detail of preferred offtake arrangements. An underlying assumption is that unless long term income is assured by some mechanism, it will not be possible to finance a commercial scale CST plant (ie. none of the respondents advocated that project developers simply build plants to operate on a merchant basis). In the words of one major international project developer *"the best outcome is an indexed PPA over around 25 years from a strong credit worthy off-taker."*

Others note that it is not necessary for off-takers to absorb technology or performance risk, as these are borne by the project developer and its EPC contractor. Underlying this is the assumption that such an off taker must have a reason to offer an offtake agreement and this will be largely based on the underlying market and policy situation.

Commentary on this aspect mirrors the discussion of CST power values vs cost and the barrier that is the lack of current reward for those values that is sufficient to make projects economic. Thus for example suggestions are made that:

- Future renewable electricity policies or schemes should reward increasing grid reliability and security with higher value certificates.
- Renewable electricity tariff support should favour generation outside sun hours and / or peak demand or wholesale price periods in general.

There was some discussion of alternative structures to offtake agreements. In the simplest version the off-taker procures the full output of electricity, LGC and any other marketable services the plant offers over a long-term period and mandates the operator on the dispatch strategy required.

A Contract for Difference has been used in many renewable energy options. The result is essentially the same as the PPA but structured more as a hedge contract, with the owner operator maximising revenue for market mechanisms and the off-taker warranting a minimum income level but also requiring a repayment where market income exceeds the warranted level.

A new model that has recently become relevant is the project owner receives a PPA contract for supply of a customer's energy as it is needed and is free to provide this with a mix of the plant's own generation along with the right to buy and sell energy in the wholesale market.

2.8. Factors differentiating projects from other technology solutions

This question in ARENA's RFI essentially elicited aspects of responses that touch on many of the issues raised also in response to other questions. Thus, in summary:

- CST power projects are bigger and more complex than wind or PV.
- CST power generation's LCOE is higher than wind or PV.
- CST power has similar system benefits as conventional steam or gas-fired power generation but with zero emissions.
- The extra values that CST power brings are not recognised with simple tariff support mechanisms such as a RET that rewards all renewable MWhs equally.

2.9. How best to support the deployment of CST

The open-ended question that was posed in the RFI on: "*any other information the respondent feels may be relevant to the ARENA and CEFC's consideration as to how best to support the deployment of CST" has* elicited some useful responses on the general area of how best the agencies / governments could support deployment.

Whilst smaller companies were advocating support for early demonstrations, experienced companies suggest that for Australia to play a part in a global industry, it needs to build utility scale (50 MW_e or larger) plants.

Various submissions point to countries that have successfully progressed CST power deployment. For example, some submissions supported South Africa's approach of carrying out reverse auctions under a tariff cap, with the addition of Time of Day multipliers. Morocco's approach was also praised for its coordinated policy and actions in the sector. Morocco is cited as an example where a balanced mix of technologies has been chosen by the government agency and then filled by specific auctions.

The advantages and cost efficiencies that flow from jurisdictions that establish solar parks or precincts pre-approved for development and connection were also recommended.

A key message repeated by many is that a pipeline of projects is needed for a country to maximise the benefits of CST power involvement. Ideally a program that establishes a pipeline of projects is needed to establish best-practice, improve local supply chains and facilitate cost reductions. Multiple projects in a location / country either in parallel or sequentially offers the benefits of lowering of risk margins from lenders, potential shared facilities, avoided mobilisation costs and establishing local supply chains. This translates to recommendations for Australia to hold a series of funding rounds for CST power rather than just one.

The track record of Spain installing 2.3 GW_e of CST capacity between 2007 and 2013 is mentioned in several submissions as illustrating the growth that can be sustained in a country, if

suitable policy settings are in place. Submissions argued that analysis of the overall economic benefit to Spain far outweighed the cost of the FiT.

One submission analysed an Australian Industry scenario that showed that at least 3 GW_e would be achievable by 2030 and that this would create 4,000 continuing jobs.

Many submissions highlight lessons that can be learnt from past experience and offer words of caution. Experienced players caution against awarding capacity auctions on price to unproven technologies and providers. A local submission discusses the failure of the previous Solar Flagships program to deliver a successful CST project as it offers lessons for the present process. It is suggested that the reasons for failure include awarding a single project to a single supplier and awarding it on price with insufficient regard to track record.

A specific suggestion for potential action by Australian Government agencies (Federal or State together) is that a total capacity of around 200 MW in three to four separate projects of 50 MW_e or more each would be an optimal outcome. Further, the process adopted should ideally involve the integrated provision of an offtake agreement via a contract for difference or other mechanism.

2.10. Project sizing (rated capacity, storage hours), location and dispatch profile

The issues of storage hours and dispatch profile were discussed in the context of likely market demand for dispatchable energy. Proponents capable of delivering CST power systems were willing to design and build these in whichever configuration between continuous output and peaking that is requested or motivated by the commercial arrangements offered.

The overall view though is that flexible operation with between 4 and 10 hours of storage is probably optimal for Australia’s main-grid. Systematic approaches to optimisation of solar field size for a given amount of storage and generation capacity and location are well established.

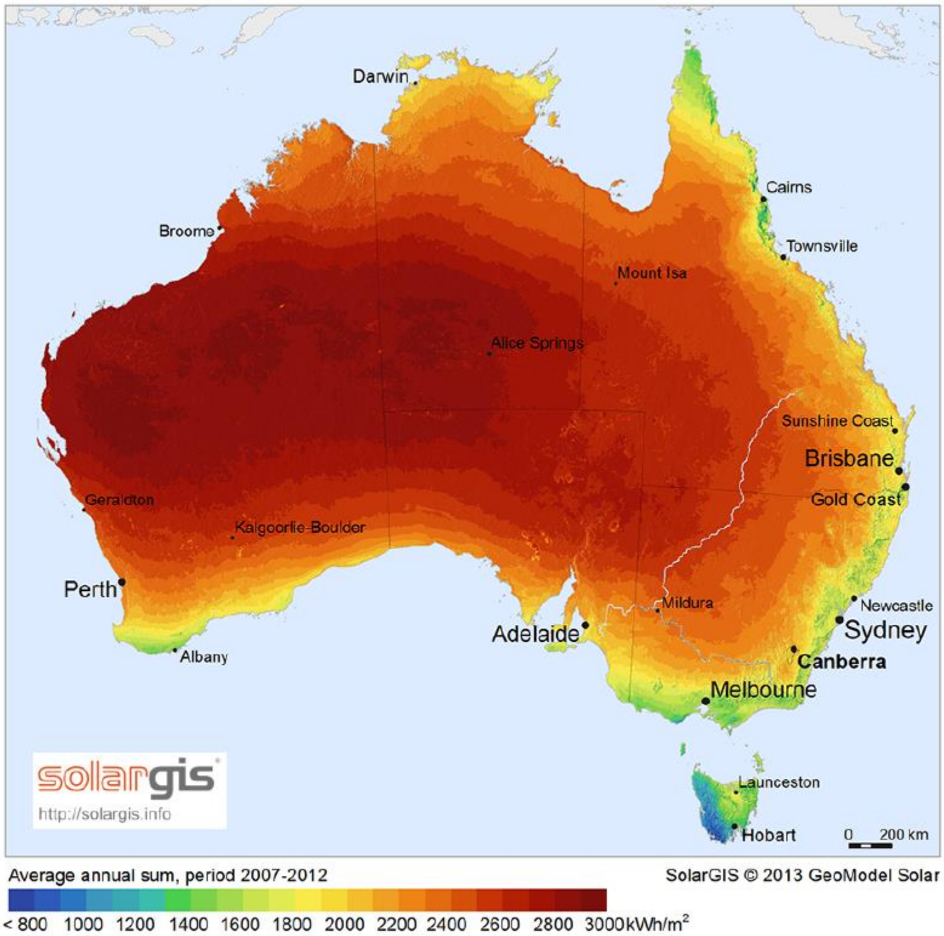

Figure 5. Direct Normal Irradiation map of Australia, (DNI Solar Map © 2016 Solargis)

Regarding location, there were implicit discussions on the various issues that would determine a preferred site choice. The level of solar Direct Normal Irradiation (DNI) resource is an obvious and major one. Australia has such good solar resources that it is less of an issue than most countries. The broad consensus is that DNI needs to be above 2,000/kWh/m^2/year. This implies that anywhere west of the great divide can be considered. It also indicates that there is considerable potential in the north of Victoria in addition to all the other mainland states.

The major issue that was discussed was around the desirable size of a CST plant regarding rated power capacity. There is a broad consensus that greater than about 50 MW$_e$ is needed because of economies of scale and that plants out to 300 MW$_e$ can readily be contemplated. Beyond that size, increasing losses in energy transport pipes or of reflected radiation from heliostats outweighs further economy of scale advantages or turbine efficiency improvements.

One of the main drivers to larger systems is that steam turbines are more efficient when they are larger, meaning less solar field needs to be built per MW of generation capacity. The need for size is well illustrated in one submission, with quoted steam turbine efficiencies from a leading supplier using steam at 530ºC and 100 bar that are 36.5% at 10 MW$_e$ increasing to 42.5% at 50 MW$_e$. Above 50 MW$_e$ there are only small further increases in efficiency. Between 1 MW$_e$ and 10 MW$_e$, Organic Rankine Cycle packaged power blocks are a better solution, offering efficiencies between 20% to 34%.

For new technologies, pilot plants can and should be built at smaller scales to reduce risk, but the lower performance and consequent higher cost of energy needs to be taken into consideration.

Australia does have a market niche of off grid and fringe of grid opportunities that could be met with systems in the 5 to 10 MW_e range. This is definitely worth considering as although the CST power LCOE will be higher, the competition of diesel generation, for example, is also higher cost.

CST process heat systems can be smaller since they are not limited by turbine efficiencies. Smaller systems (down to 1 MW_e) but used in cogeneration applications such as use of the waste heat for desalination also make sense since the lower turbine efficiency simply diverts more energy to the secondary thermal application.

2.11. Capital and operating costs

The cost discovery aspect of the RFI has been limited as might be expected. Major companies are circumspect about their competitive position until a specific competitive process that they wish to succeed in is offered. Of the 31 responses, 12 offered a view on the currently achievable LCOE range for CST. The 12 LCOE ranges that were quoted or can be deduced from the submissions were analysed and then summarised as shown in Table 2.

While an unweighted average of this data may not be optimal, it is considered to be indicative of the potential, 2017 LCOE cost range for Australia. Using this data, an indicative LCOE average for a large CST power plant in Australia would be in the range $124/MWh to $154/MWh.

Quite a few submissions from notable major experienced players declined to be specific on costs. Some more ambitions cost estimates that were provided came from the smaller technology development companies who do not yet have a track record of deployment but clearly wish to sell the potential of their approaches. Some experienced players and industry associations offered commentary based on recent international procurements and publicly available reports such as IRENA 2016[3].

Table 3. Summary of assessable LCOE cost estimates (adjusted to AUD)

Industry role (x12) – Engineering Services, Developer, EPC, Industry Associations	Approx combined across overlapping roles	Average LCOE lower estimate	Average LCOE upper estimate
Total	17,000MW_e	$124/MWh	$154/MWh

3 IRENA 2016, THE POWER TO CHANGE: SOLAR AND WIND COST REDUCTION POTENTIAL TO 2025. International Renewable Energy Agency.

2.12. Expected areas of future capital and operating cost reduction

All respondents were confident that cost reductions have been occurring and will continue. A number of experienced companies provided detailed discussions of the various areas from which they are confident cost reductions would be contributed even though they did not document their own estimate on current LCOE.

Experienced organisations offer a detailed discussion of costs and cost reduction trajectories. Discussion of recent bids from Dubai, support a view that prices below 100 Euro per MWh may already be achievable. There is reference and implicit endorsement of the findings of IRENA 2016 that suggests a 35% cost reduction by 2025 (see Figure 6). Some submissions discuss in detail the source of cost reductions expected. Commentary on the strong local content expectations was also provided.

It was suggested that CST energy costs have more than halved in the last ten years. The total 5 GW_e of CST capacity globally is compared to the 300 GW_e of PV and it is noted that when PV was at 5 GW_e of deployed capacity in 2004, its LCOE was ten times that of CST today. With just 5 GW_e installed so far, CST power is at the beginning of its cost curve.

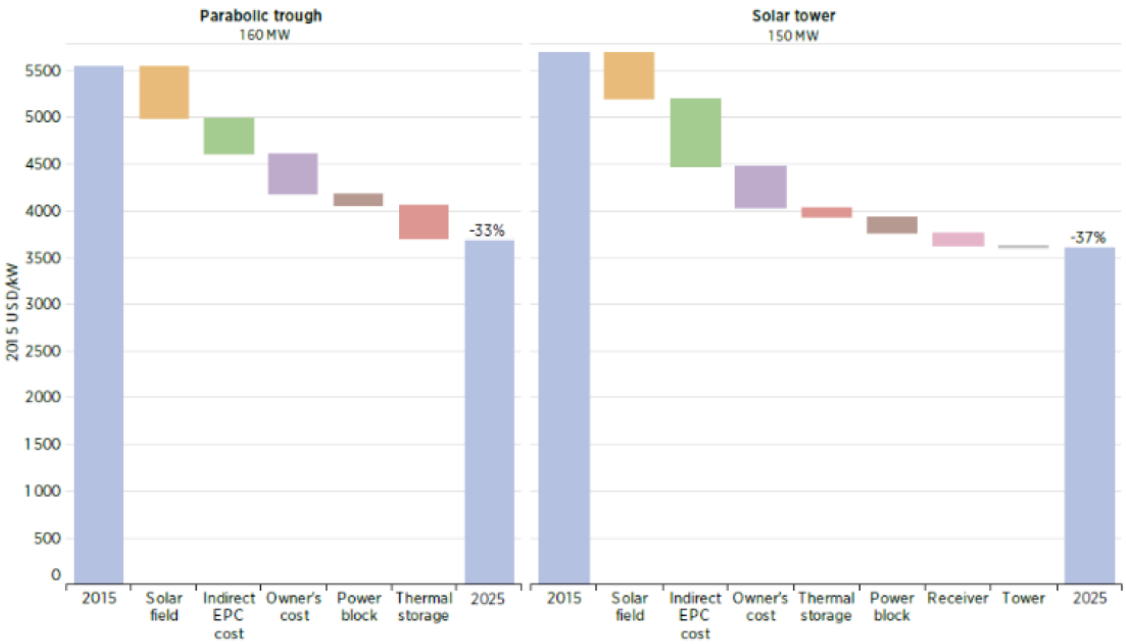

Figure 6. Trough and Tower cost reduction potential by source, from IRENA 2016 as referenced by respondents.

Anticipated technology improvements

Cost reductions can come from direct reductions in the cost of manufactured items but also from improving the performance of components such that more electricity is generated from the equivalent hardware. In this regard input from several submissions is of note.

Many suggest that towers offer higher efficiencies than trough systems via higher concentration and operation at higher temperatures. Further to this, the direct heating of molten salt and its simultaneous use as a thermal storage medium also improves efficiency and economics. Among tower advocates, there is a dichotomy between those advocating large single installations vs distributed modular multi-tower systems.

R&D for cost and performance also notably includes efforts to reduce system start up times and increase flexibility, through working with steam turbine manufacturers. A number of respondents discussed the concept of CST with salt storage plant hybridised with a gas turbine system for maximum firm generation. This was reported as the aim of the EU funded project called 'Hysol T&I'.

Anticipated capital cost reductions

The industry associations plus the more experienced companies discussed specific areas for improvement by subsystem and components. A good example is the following list of areas of potential for cost reduction:

"Solar Field

1. Collector with larger aperture (trough)
2. Improved optics through higher accuracy heliostats, improved field layout (tower)
3. Advanced assembly procedure, industrialised assembly, industrial automatization in manufacturing: (sub) supplier standards: standardized design
4. Higher reflectivity, higher cleanliness
5. Improved durability
6. Improved absorber coating
7. Wireless power supply and control (heliostat)
8. Improved optics through higher accuracy heliostats, improved field layout (tower)
9. Improved O&M procedures.

Thermal Storage

1. Direct storage concept (HTF = Storage Medium)
2. Higher temperature difference
3. Adapted thermal storage materials
4. Standardized design: sub supplier standards
5. Advanced charging and discharging, improved operating strategies in general

Power Block

1. Higher cycle efficiency
2. Improved hybridization concept
3. Larger power block
4. Standardized design

System Efficiency

1. Higher process temperature
2. Lower parasitic consumption (higher temperature through larger aperture and other HTF at the tower; gravitational pressure loss recovery)
3. Adapted turbine design (for daily startup)
4. Improved control and O&M strategies / procedures"

2.13. Other Aspects of CST projects

Potential to develop the local supply chain &

Expected local content and the potential for local industry development

The overall consensus was that around 60 to 70% local content in project value can be expected and this will be larger over time if there is a pipeline of projects. Many respondents were confident that CST will bring greater local content to Australia than PV or wind projects do. Some specific observations on this aspect included:

- For a 100 MW_e plant, the responses indicated the creation of between 3,000 and 4,000 direct and indirect jobs with around 1,000 skilled construction workers on site can be expected during construction. Once commissioned, a much smaller, permanent workforce is required for ongoing operations. It was noted that most people are employed in the state that the plant is built in.
- Experience with US projects suggests that such a project is also likely to involve over 100 subcontractors, the large majority of which (around 80%) would come from within the country where the plant is being built.
- For the development of an Australian CST Industry, another submission suggested at least 3,000 MW_e would be achievable by 2030 and that this would create 4,000 continuing ongoing jobs from both operation and the pipeline of construction. They provide a nice specific analysis of the components that are inherently local vs those that must be imported.
- One submission provided a very informed categorisation of the value chain and project roles that are encountered that could be mapped to local capability.
- Another submission provided some interesting specific illustrations of the local content aspects achieved in South African CST power projects.

Expected annual energy output

Some respondents quote annual electricity output that might be expected for a plant. These figures are a key input to LCOE calculations.

There is a major reduction (around 50%) of output from summer to winter for the southern areas of the continent that should be noted. Sites in Queensland for example, would be expected to have a much more even production through the year. In the South Australian context however, this seasonal variation correlates well with the most challenging summer peak loads.

Likely construction and commissioning timeframes

In Spain, during the peak of construction where multiple similar 50 MW trough plants were built by experienced teams and contractors, construction times from ground breaking to grid connection were reduced to 18 months.

For tower plus molten salt plants in Australia at the present time, there seems to be a consensus that around 30 months is required. A few of the more experienced companies offer detailed listing of the timing and steps needed in such a construction schedule, based on their extensive experience across many projects. It should be noted that the first power generation might occur at around 20 months.

The construction phase follows a project development phase that can be quite extended. Actions by state and federal agencies can work to speed this phase.

Potential grid impacts.

Grid impacts of CST power systems are considered to be overwhelmingly positive. Indeed, they are an alternative way of considering the value proposition as discussed in Section 2.2.

A paraphrased adapted summary is:

- **Reducing Wholesale Power Prices**
  By aiming to generate when prices are high, CST power plants reduced price volatility in the electricity market and lower long-term average prices. Energy not sold would be lost (if the storage is full) so there is little incentive to withhold generation to manipulate the market.
- **Increasing Reliability**
  CST power plants complement variable renewable energy technologies, enabling higher renewable instantaneous penetration and annual contribution while augmenting grid stability and reliability. CST power plants produce smooth output and can adjust production to compensate for fluctuations in other technologies.
- **Lowering Emissions Intensity**
  CST power plants provide generation that is a direct replacement for coal and gas plants but with zero greenhouse gas emissions and pollution. It can potentially lower emissions more that the same amount of VRE generation since the latter can trigger behaviour changes in fossil fired plant that can make their average emissions higher.
- **Reducing Network Losses**
  Locating CST power plants towards the fringe-of-grid, which has traditionally been the furthest from generation centres, reduces system transmission and distribution losses.

3. CONCLUSIONS

ARENA's RFI on CST has resulted in 31 responses that between them build on experience from every significant CST power system that has so far been completed globally. Many of these responses provide detailed analysis against ARENA's RFI questions and represent a significant investment of effort by the respondents. That in itself is an indication that those who respond are keen to be involved in growing CST in Australia. Some companies both large and small have explicitly indicated that they have plans for projects they would like to progress.

Overall, the views expressed are very positive on the future of CST. All referred to the key advantage of cost-effective, integrated thermal energy storage and the characteristics of dispatchable generation via synchronous generators. There is a consensus in the responses that although a CST power plant's LCOE is higher than that of wind or PV without storage, the extra values that CST brings to the system more than justify the extra cost.

In this regard, it is significant that a range of major international engineering companies who are in a sense technology neutral and have a track record of involvement in a range of renewable technologies including large PV projects, remain strongly supportive of CST's potential.

The RFI did not explicitly ask for specific proposals. Whilst some respondents did describe specific project ideas, most did not. At the same time, they did not state categorically that they did not have specific plans. An unanswered question is how long it would realistically take suitably qualified companies to produce a detailed project proposal for a competitive process.

Absent from the responses were:

- Responses from major technology agnostic global renewable energy project developers.
- Any responses from China.
- Responses from Australian State or Territory governments other than Victoria.

Irrespective of this, it is clear that any large scale competitive process to advance CST power generation in Australia would be well subscribed by a critical mass of experienced companies as well as smaller players seeking to progress towards commercialisation. It should also be remembered that there are also significant opportunities for CST technologies to provide process heat for industrial sites.

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