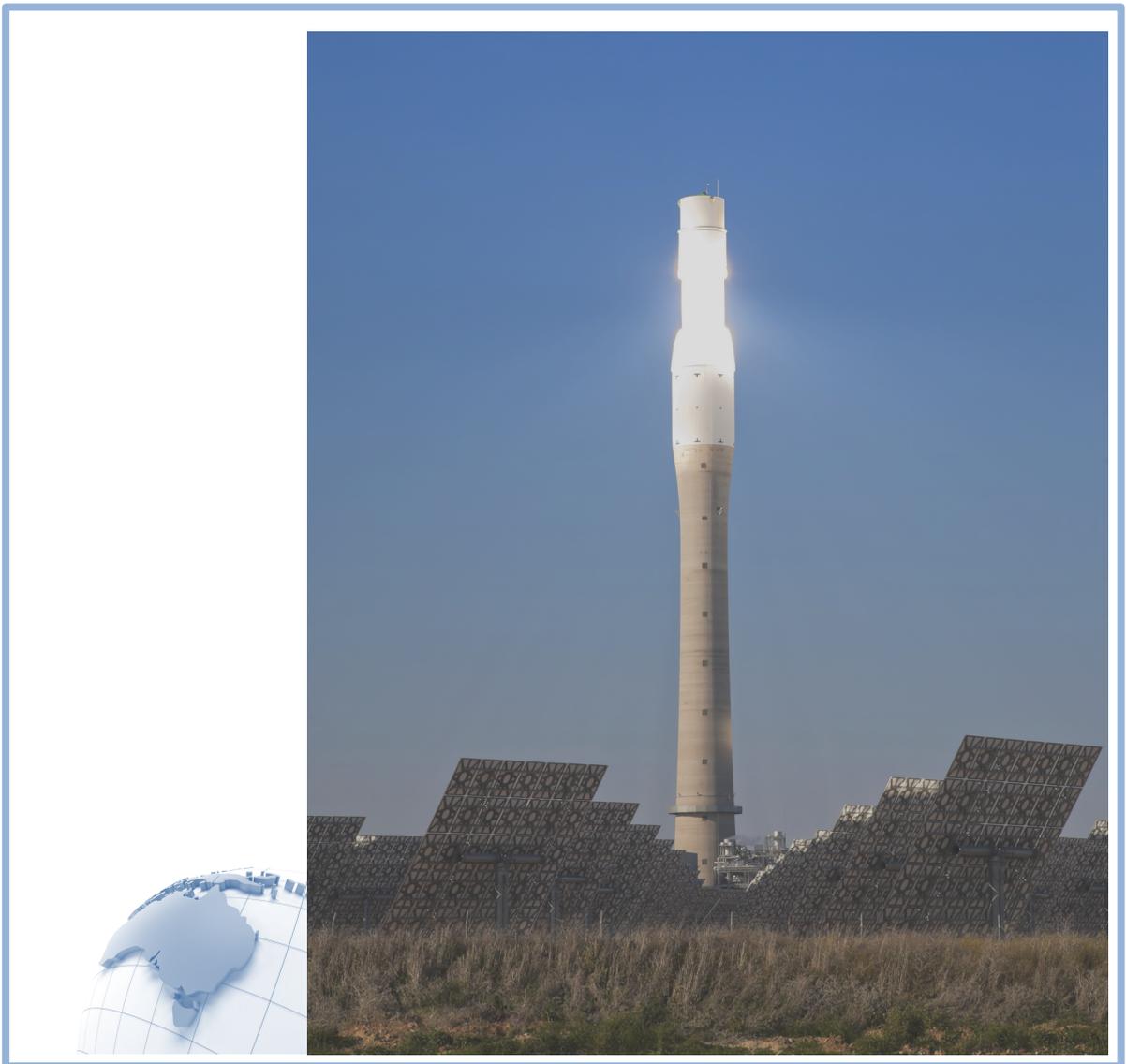




JEANESHOLLAND
AND ASSOCIATES

Australian Concentrating Solar Thermal Industry Roadmap



Australian Concentrating Solar Thermal Roadmap



August 2018

Disclaimer:

This Report provides a Roadmap developed to inform the future decisions of stakeholders in the CST sector and the Australian energy sector more broadly.

The Roadmap's development involved extensive stakeholder engagement and detailed modelling of the physical and behavioural aspects of the National Energy Market using historical, current and forecast data. Forecast input data has been sourced from multiple parties using the most authoritative sources available. Where adjustments have been made to the forecast data used, it has been towards more conservative assumptions that, in the view of the authors, was prudent.

The nature of this, and any, Roadmap of the future is based on assumptions and these have been set out clearly.

The Roadmap, supported by ARENA, represents the considered views of the authors, informed by subject matter experts commissioned to do specific work (see Appendix 4), as well as stakeholders and numerous previous, relevant reports. It does not necessarily represent the views of ARENA or the parties listed in Appendix 4.

Australian Concentrating Solar Thermal Roadmap

Table of contents

1	Executive overview	5
2	Background	10
2.1	The Finkel blueprint	14
2.2	Ancillary and other services	14
2.3	The emergence of energy storage technologies	15
2.4	Low cost – rewarding customers	16
2.5	CST as a contributor to the Finkel blueprint four key outcomes	16
2.6	The Australian experience and emerging global developments	17
2.7	Process heat	18
2.8	Research	18
2.9	Roadmap approach and consequential direction	19
2.10	Policy landscape	20
2.11	Jargon	20
3	Concentrating solar thermal technology	21
3.1	Introduction	21
3.2	History of CST in Australia	22
3.3	CST globally	23
3.4	Economics of CST in Australia today	24
3.5	CST and electricity networks	24
3.6	Large-scale CST	25
3.7	Smaller-scale CST	26
3.7.1	Overview	26
3.7.2	Fringe-of-grid distribution connected CST	27
3.7.3	Behind-the-meter CST	27
3.7.4	Off-grid CST systems	28
3.7.5	Combined heat and power	29
4	Energy market economic analysis	31
4.1	Background	31
4.2	Scope and approach	31
4.3	Assumptions	31
4.4	Modelling results	32
4.4.1	Market sizing	33
4.4.2	Deployment timing	34
4.4.3	Customer bill savings	34
4.4.4	Entries and exits	35
5	Capturing value	37
5.1	Modelling scenarios – Justifying a Roadmap	37
5.2	Headlines	37
5.3	Scenario results reveal logical pathway	38
5.4	Competitiveness with other dispatchable technologies	40
5.5	Comment on value of ancillary services	42
5.6	Emissions reductions	42
5.7	Low-hanging fruit for early deployment	44
5.8	The rationale for incentivising early deployment	45
6	Industry development	45
6.1	The CST value chain and Australian businesses	46

Australian Concentrating Solar Thermal Roadmap

6.2 Spillovers	46
7 Indirect economic benefits.....	47
7.1 The economic model.....	47
7.2 Base Case	48
7.3 No Regrets Case	48
7.4 Base Case versus No Regrets Case	49
8 Stakeholder consultation	50
8.1 CST developers.....	50
8.2 Finance sector	50
8.3 Electricity sector.....	51
8.4 State governments.....	51
9 Three key focus areas	52
10 Recommendations	53
10.1 FOCUS AREA 1: Smaller systems connected in the distribution network and off-grid	53
10.1.1 ARENA Initiatives	53
10.1.2 Government initiatives.....	57
10.2 FOCUS AREA 2: Research, development and early demonstration	61
10.2.1 ARENA initiatives.....	61
10.2.2 ARENA/ASTRI joint initiative	62
10.3 FOCUS AREA 3: Widespread uptake of CST systems - A contribution to the four Finkel outcomes	63
10.3.1 ARENA initiatives.....	63
10.3.2 Government/regulatory initiatives	63
10.4 Initiatives for CST industry to consider	65
10.4.1 Think small to begin with	65
10.4.2 Target high-value locations	65
10.4.3 Consider CHP behind-the meter applications.....	66
10.4.4 Economically optimise configurations	66
10.5 Recommendations summary	67
11 Roadmap timetable	68
11.1.1 The objective	68
11.1.2 The two-year plan	68
11.1.3 Five-year plan.....	68
11.1.4 The ten-year plan	69
11.1.5 Timeline.....	70
Appendices.....	71
1. Concentrating Solar Thermal Technology Status – ITP Thermal Pty Ltd	72
2. Concentrating Solar Power Market Modelling – Energeia Pty Ltd.....	73
3. Industry Development Opportunities from Concentrating Solar Thermal Power in Australia - Australian Industrial Transformation Institute.....	74
4. Acknowledgements.....	75
4.1. Lead contributors:.....	75
4.2. Stakeholder consultation	76
4.3. Expert advice.....	78
5. References	79

Australian Concentrating Solar Thermal Roadmap

1 Executive overview

The challenge

In October 2016, the Council of Australian Governments (COAG) Energy Council (Energy Council) sought a blueprint to underpin the orderly transition of the national energy system. The need for a blueprint came about because of an increasing number of concerns from stakeholders arising from interruptions to supply across the market due to a vast range of rapid and transformative changes.¹ The Energy Council believed these changes should be managed better and in a coordinated way.

The Energy Council appointed a panel of experts, headed by the Chief Scientist Professor Alan Finkel, to undertake a review of the National Energy Market (NEM) and produce a blueprint for its future. The expert panel released its final report, *Independent Review into the Future Security of the National Electricity Market: A blueprint for the future* (Finkel Review) in June 2017. The Finkel Review focussed on delivering four key outcomes for Australia's electricity consumers: increased energy security, future reliability, rewarding consumers with lower costs and reducing emissions.

The Finkel Review found that:

New variable renewable electricity (VRE) generation is being incentivised and brought forward by the Renewable Energy Target but other investment has been lacking. This is a problem because, at present, a certain amount of dispatchable capacity is required to maintain system reliability. Capacity is dispatchable if it can respond to electricity demand on call. Dispatchable capacity can be provided by a range of sources, including dispatchable generation (for example, coal, gas, hydro, solar thermal, and biomass), interconnectors, storage and demand response mechanisms.²

This concern about the need for dispatchability to maintain system reliability has been echoed in other advice to government including several recent and significant reports into the national energy system, such as:

- written advice from the Energy Security Board (ESB) to the Minister for Environment and Energy in October 2017³
- the Australian Energy Market Operator (AEMO) *National Integrated System Plan for the National Electricity Market* (ISP) released in July 2018⁴

¹ "The industry is now experiencing the simultaneous effects and benefits of digitalisation, ageing infrastructure, a markedly and rapidly changing cost structure in both supply and storage, flattened and even negative demand growth, the impacts of climate change, cyber security concerns, and a profound change in consumer preferences and expectations for the industry." *National Integrated System Plan: for the National Electricity Market*, AEMO, July 2018, p.3.

² *Independent Review into the Future Security of the National Electricity Market: A blueprint for the future*, Professor Alan Finkel et.al., p.76.

³ <http://www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/Energy%20Security%20Board%20ADVICE...pdf>, p.3.

⁴ www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan, p.6.

Australian Concentrating Solar Thermal Roadmap

- the Final Report of the Australian Competition and Consumer Commission (ACCC) Retail Electricity Pricing Inquiry, *Restoring electricity affordability and Australia's competitive advantage* released in July 2018⁵.

The ISP, which was developed in response to Recommendation 5.1 of the Finkel Review, highlights the need for a portfolio approach for the future including utility-scale renewable generation, storage technologies, flexible thermal supply and distributed energy resources (DER) in order to facilitate the orderly transition.

Concentrating solar thermal (CST) is one of the few technologies that can provide this range of attributes.

The opportunity

Australia will require utility-scale renewable generation and storage into the future. There are several potentially viable technology solutions that could meet this requirement, each with their own strengths and weaknesses.

The purpose of this Report is to interrogate the case for the deployment of one such technology, namely CST with storage in Australia. This interrogation is important because:

- The need for dispatchable electricity is increasingly being recognised and CST is one of the few, non-emitting dispatchable technologies identified in recent reports as a potential solution to maintaining security and reliability.
- Australia has limited experience with CST deployment.
- Recent global developments are resulting in the increased deployment of larger CST systems with storage to better assess the cost and performance of systems.
- The global research and development effort on CST is increasingly coordinated and focussed on increasing system efficiencies and reducing system costs.

This Report does not prosecute the case for CST but aims to establish and quantify the technology's potential value to the national energy system beyond its Levelised Cost of Energy (LCoE), and hence its value to consumers. Where a case for support is established, the Report sets out a Roadmap to capture the values of CST for the energy system through targeted deployment for federal, state and territory governments, regulatory bodies, CST developers and broader energy sector stakeholders to consider.

The approach

Jeanes Holland and Associates (JHA) brought together acknowledged experts in relevant fields to contribute to the interrogation process. Co-contributors to this Report are: Energeia, specialist energy market analysts based in Sydney; ITP Thermal (ITP), CST energy technology specialists based in Canberra; and the Australian Industrial Transformation Institute (AITI), industry development specialists based at Flinders University in Adelaide. The four entities and ARENA comprised the Report's Steering Committee.

Global CST technology costs were updated and configured into Energeia's whole-of-power system simulation platform, uSim, which uses a bottom-up approach to consider

⁵www.accc.gov.au/publications/restoring-electricity-affordability-australias-competitive-advantage, p. v.

Australian Concentrating Solar Thermal Roadmap

consumer behaviour; electricity network assets, capabilities and costs; existing and viable new generator technologies; storage technologies; and fuel costs.

Four scenarios were modelled:

- Low Case
- Base Case (mid-range deployment)
- No Regrets Case (mid-range deployment with no- or low-cost measures)
- High Case.

The findings

Details of the assumptions included in each scenario can be found in Chapter 4. The interrogation produced the following headline findings:

Base Case

- Under the Base Case (no change to current policies, targets or plans) the economics of CST would see 3.94 GW of CST projects pulled into the transmission network from 2031 through to 2040 as it becomes the lowest-cost replacement for existing coal. This economically-driven entry of CST would reduce customer power bills by \$2.0 billion (2018\$) and drive \$2.4 billion in new economic activity, creating more than 13,000 FTE years of employment over the same period.
- Australia would get optimum reliability, emissions reduction and economic outcomes with early deployment of smaller CST systems in specific areas of the distribution network and in off-grid locations ahead of the supply and reliability pressures caused by coal exits 2030.

No Regrets Case

- The No Regrets Case would require minimal policy intervention by transferring network cost savings to smaller distributed generators in fringe-of-grid locations. It would result in an additional 1.14 GW of CST between 2022 and 2040 across regional Australia, an additional \$1.1 billion reduction in consumer power bills to the Base Case, an additional \$2.8 billion (or \$5.2 billion in total) of new economic activity and more than 28,000 FTE years of employment.
- Some energy users in fringe-of-grid locations would be able to leave the grid while maintaining current AEMO reliability standards and either maintaining or reducing customer bills, as well as increasing the reliability of the NEM.
- The optimal configurations in these locations would include a hybrid of photovoltaics (PV) with a small battery capacity to manage transitions, CST and a standby diesel system. Separation from the grid could be staged so that the connection is not severed until security and reliability are proven.
- From 2025, off-grid communities and mines would take up an estimated 0.60 GW of CST in configuration with PV, batteries and diesel as the least cost reliable supply option.
- The uptake of CST in fringe-of-grid locations, as part of a hybrid energy system, would also help to reduce cost, financing and technical risk associated with deployment of large utility-scale systems post 2031.

Australian Concentrating Solar Thermal Roadmap

Overall

- Australian industry has the capacity to adjust for, and fully engage in, the CST sector domestically and globally.
- Australian research institutions, facilitated by the Australian Solar Thermal Research Institute (ASTRI), will continue to play a vital role domestically and globally in the advancement of CST technologies that will be key enablers of more efficient and cost effective systems in the future.
- There is an immediate opportunity for combined heat and power (CHP) systems to provide both heat and electricity to regional energy intensive industries such as food production and processing. Modelling for CHP was not undertaken for this report as each situation is highly bespoke, but several projects are already in the development stages. Sundrop Farms, Australia's largest glasshouse and a producer of tomatoes in South Australia, is already operational using CST technology.
- Without the entry of CST into the NEM, Australian consumers will be paying more for electricity through to the end of 2040. From 2031 CST will be the cheapest dispatchable technology available to support the growing deployment of VRE technologies.

Based on the modelling, analysis and extensive stakeholder feedback undertaken for this Report, JHA has developed a Roadmap for CST deployment that focuses on the benefits delivered to the NEM and Australian consumers if the No Regrets Case is adopted.

The benefits of the No Regrets Case justify the facilitation of CST's entry into the Australian energy system. This would secure optimum outcomes for system security and reliability, while meeting current emissions targets at lowest cost for consumers.

The NEM will look very different in 2040 than it does today. The transformation is already underway *"with the last decade seeing a significant increase in the uptake of new technologies such as rooftop solar photovoltaic systems, battery storage and 'smart' energy management systems at the distribution level (often collectively referred to as distributed energy resources or DER)"*.⁶

VRE will be supported by storage technologies, improved energy management practices, and new dispatchable generation technologies such as CST to ensure that electricity is available when customers want to use it. In addition, as indicated in the modelling undertaken for this Report, without CST in the NEM consumers will pay more to achieve the same level of reliability and emissions reductions.

These technological changes will also need new business models supported by evolving regulatory regimes to provide the best outcomes for customers.

Accordingly, the Roadmap proposes a staged approach for the development of the CST sector in Australia. It also identifies a number of potential initiatives for government and the relevant regulatory bodies, the CST industry and broader energy sector, and the research community to consider.

⁶ www.aemc.gov.au/sites/default/files/2018-07/Final_Report.pdf , p.ii.

Australian Concentrating Solar Thermal Roadmap

The key recommendations

These key recommendations are proposed to capture the value uncovered in the Report findings:

1. Implement a mechanism to reward distributed generators with a proportion of the network savings they produce as a cost-neutral incentive to accelerate the benefits of the deployment of CST and other DER technologies, particularly in fringe-of-grid distribution networks. The Australian Energy Market Commission (AEMC) is currently reviewing the economic regulatory framework and the Australian Energy Regulator (AER) is reviewing the application guidelines for the regulatory investment test. Both activities are highly relevant to this recommendation.
2. Provide funding support for a small number of small to mid-size CST systems⁷ to demonstrate the technical capabilities and economics of CST systems embedded in fringe-of-grid locations and systems where high network costs could justify a shift to off-grid generation. This would simultaneously build industry capacity in regional locations and provide scalable experience for Australian stakeholders including financial institutions, project developers, constructors and operators to assess. It would also accelerate benefits to consumers and regional economies.
3. Provide specialised assistance such as ‘design for manufacture’ expertise to reduce the costs of early Australian technologies.
4. Drive better collaboration between researchers and industry through ASTRI.
5. Support the underwriting of power purchase agreements (PPAs) with smaller retailers and suitable corporate off-takers to increase competition for bankable off-take agreements.
6. Facilitate work with potential off-takers and generators to drive a more equitable alignment of PPA pricing with time-of-day generation and dispatchability benefits to encourage and reward peak-focussed dispatch.

⁷ Throughout this Report, small systems including pilot systems are highly bespoke and generally considered in the 1-5 MW range. Systems in the 5-30 MW range are referred to as mid-size systems and are able to fit within the constraints of the distribution network. Large systems are considered as over 30 MW and connected within the transmission network. Systems up to 30 MW are referred to as smaller systems to highlight that there are many bespoke opportunities for deployment across the distribution network and off-grid, which are not transmission connected. These larger systems are widely referred to across the energy sector as utility-scale.

Australian Concentrating Solar Thermal Roadmap

2 Background

Since the 1990s when the world first came together through the Kyoto Protocol process to develop a global plan to reduce greenhouse gas emissions, successive Australian, state and territory governments have introduced a range of economy-wide measures to reduce emissions. These measures included initiatives focused on reducing emissions across the nation's energy systems.

The Kyoto Protocol set national targets for the first commitment period (through to 2020) and Australia is on track to meet its commitment to reduce emissions by five per cent below 2000 levels by 2020. This is equivalent to 13 per cent below 2005 levels.⁸

In 2016, nations reached agreement in Paris on a second round of emissions reduction targets with Australia committing to a target of 26-28% below 2005 levels by 2030.

The introduction of the measures developed by Australian governments coincided with a vast range of changing conditions occurring across the nation's electricity markets. These changing conditions included the de-aggregation of electricity market segments across the NEM states, the ageing of our predominantly coal-fired electricity generation fleet and dramatic changes in the global demand for, and price of, gas.

The changes also included the impact of consumer actions such as the rapid installation of air-conditioning systems and the adoption of new energy generation and management technologies, primarily rooftop PV systems, to enhance consumer electricity independence. Increasingly throughout this current period of the transition, consumers are complementing their rooftop PV systems with behind-the-meter batteries to further enhance their energy autonomy.

Energy supply is utilised in three forms: electricity, transport fuels and heat. As Australia's supply of energy across these three areas has largely come from the burning of fossil fuels, our energy use produces high levels of emissions per capita. Our single highest source of greenhouse gas emissions across the energy sector comes from the use of electricity.

In recent years, public debate on emissions reduction has focused on electricity. This is perhaps because Australians have such a fundamental relationship with electricity through its direct supply to our homes. Electricity's domination in the debate has two major and related matters of contention at its heart:

- Despite the overwhelming evidence and the consensus among climate scientists that there is a direct correlation between the increasing saturation of the atmosphere with greenhouse gases and increasing global temperature, there are still those who do not accept this evidence and consensus.
- An emissions-reduction change in an established system that delivers a service such as electricity is likely to come with a short-term cost impact, so those who do not accept this evidence and consensus argue that any costs incurred through efforts to reduce emissions are unnecessary.

⁸ <https://www.environment.gov.au/system/files/resources/c42c11a8-4df7-4d4f-bf92-4f14735c9baa/files/factsheet-australias-2030-climate-change-target.pdf>

Australian Concentrating Solar Thermal Roadmap

This second contention has not only contributed to difficulty in getting agreement between governments on the quantum of emissions reduction and measures required to achieve it across the Australian economy, it denies the reality that ageing infrastructure is in an evolutionary replacement cycle. The process of replacing this infrastructure is underway around the world, requiring billions of dollars of investment in cleaner energy generation technologies. This investment in new generation infrastructure has seen massive global growth in the deployment of renewable energy technologies, resulting in such significant cost reductions that some forms of renewable energy are rapidly becoming the cheapest form of replacement infrastructure⁹.

Australia's major incentives to reduce emissions produced from the national electricity supply system have also focused on increasing the supply of renewable energy. These incentives have been delivered through Renewable Energy Target (RET) schemes at the national level and a number of smaller state and territory schemes.¹⁰

The incentives delivered through these schemes have focused on delivering lowest-cost electricity into the system where cost has largely been a calculation of the LCoE. The focus has not been on an evaluation of the value of the new electricity supplied into the system.

⁹ Bloomberg New Energy Finance, March 28 2018: <https://www.bloomberg.com/news/articles/2018-03-28/fossil-fuels-squeezed-by-plunge-in-cost-of-renewables-bnef-says>

¹⁰ Commonwealth and NEM state schemes:

- In 2000, the Commonwealth passed legislation to introduce the Mandatory Renewable Energy (MRET) Scheme, setting the target at 2% by 2010. After consultation with industry the target was set at 9500 GWh and the Scheme commenced on 1 April 2001. The Scheme has undergone a number of changes following reviews and government policy changes. In 2009, legislation was passed to set the target at 45,000 GWh by 2020 and since January 2011 the RET scheme has operated in two parts: the Large Renewable Energy Target (LRET) and the Small-scale Renewable Energy Scheme (SRES). In 2015, the target for large-scale generation was set at 33,000 GWh in 2020, predicting that about 23.5% of Australia's electricity generation in 2020 will be from renewable sources. <http://www.environment.gov.au/climate-change/government/renewable-energy-target-scheme>
- In June 2016, the Victorian Government committed to state renewable energy generation targets of 25% by 2020 and 40% by 2025. The targets are backed by the *Renewable Energy (Jobs and Investment) Act 2017*. www.energy.vic.gov.au/renewable-energy/victorias-renewable-energy-targets
- The Queensland Government established an expert panel to conduct a public inquiry into a state renewable energy target, which confirmed a target of 50% renewables by 2030. The target is not currently backed by legislation and will be reviewed in 2019. www.dews.qld.gov.au/electricity/powering-queensland-plan
- In 2009, the South Australian Government set a renewable energy target of 33% by 2020. This target was achieved in 2013-14 so a new target of 50% by 2025 was set in 2014. The target is identified in legislation and embedded in the state's Strategic Plan but penalties are not applied in the legislation for non-compliance. <http://www.renewablessa.sa.gov.au>
- New South Wales has a *Renewable Energy Action Plan* and supports the former national target expressed in percentage terms of 20% by 2020. www.resourcesandenergy.nsw.gov.au/energy-consumers/sustainable-energy/renewable-energy-action-plan
- In 2016, the ACT Government legislated a new target to obtain 100% of its electricity from renewable sources by 2020, from within the ACT and across the NEM. The ACT uses a reverse auction mechanism to contract its energy supply from renewable energy projects. http://www.environment.act.gov.au/_data/assets/pdf_file/0007/987991/100-Renewal-Energy-Tri-fold-ACCESS.pdf
- Tasmania has a renewable energy goal of 100% by 2022. <https://www.climatecouncil.org.au/uploads/9a3734e82574546679510bdc99d57847.pdf>

Australian Concentrating Solar Thermal Roadmap

Since the early 2000s when these incentives schemes were first introduced, electricity generated from wind and, more recently, PV systems has dominated the supply of new electricity delivered into the national system. This has resulted in an increase in the supply of intermittent or variable renewable energy (VRE), as wind and solar resources are not available 24 hours a day, 365 days a year.

This variability has resulted in a number of challenges to the supply and demand balance in the grid. The electricity output from wind systems has little correlation with the time of day use in the national market. Further, the output from solar PV systems is more aligned with daily consumer usage patterns, but is still interrupted by overcast conditions and increased demand requirements later in the day after the solar radiation has peaked.

Recognising that the challenges ahead were much broader than those brought on by increased levels of VRE alone, in 2017 the Energy Council appointed an Expert Panel chaired by Australia's Chief Scientist Dr Alan Finkel AO to develop a blueprint to underpin the orderly transition of the national energy system. Other members of the Finkel Review panel were Ms Karen Moses, Ms Chloe Munro, Mr Terry Effeney and Professor Mary O'Kane AC.

The Finkel Review focussed on four key outcomes: energy security, reliability, and emissions reduction at lowest cost. It found that additional firm capacity in the form of dispatchable energy would be required to ensure reliability as the level of VRE increases.

By aligning the cycles of VRE supply and demand with additional capability or infrastructure to ensure system security, the Review found this would in turn enhance dispatchability, or the reliability of supply, in the energy system to ensure electricity could be dispatched to consumers when needed.

Several recent analyses have considered levels of VRE penetration that could be reached without compromising system security and reliability.

The Australian Council of Learned Academics (ACOLA) in its recent report, *The Role of Energy Storage in Australia's Future Energy Supply Mix*, concluded "at an aggregated national level, Australia can reach penetrations of 50 per cent renewable energy without a significant requirement for storage to support energy reliability"¹¹. Importantly, the ACOLA report also found there was not a simple, definitive ratio for the amount of VRE versus dispatchable energy. A range of factors would impact on the ratio including the existing technology mix, intra-state restrictions due to network constraints, and export restrictions due to the capacity of interconnectors.

Both the Finkel Review and the ACOLA report concur that a level of dispatchability is required to ensure system security and reliability, and that this level rises exponentially with the increasing level of VRE over 50 percent.

Importantly for this Report, AEMO's consideration of future power system requirements in the context of the energy transition calls for the adoption of new technologies that

¹¹ ACOLA, *The Role of Energy Storage in Australia's Future Energy Supply Mix*, 2017, p.39.

Australian Concentrating Solar Thermal Roadmap

provide the services that are currently provided by thermal generation from a range of sources including new sources of dispatchable generation¹².

At this point in time, as Australia transitions towards a low carbon economy, it is important that investment decisions are made in energy infrastructure projects that reflect the need for low-cost, sustainable energy that meets system security and reliability requirements. The focus of the national bodies charged with running our energy supply systems is now firmly turning to new measures that inform these investment decisions.

There can be no doubt that the cost, reliability, security and sustainability of the supply of energy in Australia is critical to our economic and social wellbeing. Strategies to address the external impacts and sub-optimal impacts of the transformation of the system are at the centre of actions being taken by governments through the Energy Council.

A key challenge is how to integrate increasing levels of VRE into the system while simultaneously maintaining system security and supply reliability. The impending closure of coal-fired generation assets over the coming two decades on the basis of both age and emissions performance has been at the centre of much of the national energy debate and the cause of many studies. These closures will be staged over the coming decades and require investment in projects that not only replace their capabilities, such as generation, storage and ancillary services, but also contribute to Australia's committed emissions reduction targets. CST is one of several options that can provide these benefits, and is arguably the most prospective technology on the horizon that can provide them all.

The purpose of this Report is to make a considered contribution to evaluating CST's role in meeting this key challenge and proposing a pathway for development if that role is found to be a beneficial one. This Report is not intended to be a promotion for CST; it acknowledges that CST is one of several technologies that can provide energy storage or dispatchable energy. Each technology has differing strengths and weaknesses in the transition and future energy supply context.

This Report adopts a technology/cost optimisation approach to evaluate CST's performance on security, reliability and sustainability requirements so that the market provides the cheapest options for consumers.

The cost of energy is a major driver behind the well-being of Australia's economy and households. This Report investigates whether CST is a part of the lowest-cost pathway for NEM consumers to be supplied with secure, reliable and sustainable electricity.

The Finkel Review produced the blueprint required by the Energy Council to pull the above-mentioned factors together to underpin our energy transition. The blueprint provides a clear strategy comprising 50 recommended actions to see Australia through this transformation process.

¹² www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf, p.62.

Australian Concentrating Solar Thermal Roadmap

2.1 The Finkel blueprint

The Finkel Review Panel in its Final Report to the Energy Council made 50 recommendations to deliver on its four key outcomes, 49 of which were unanimously accepted. The recommendations were made across seven themes:

1. Preparing for next summer
2. Increased security
3. A reliable low emissions future – the need for an orderly transition
4. More efficient gas markets
5. Improved system planning
6. Rewarding consumers
7. Stronger governance.

A further recommendation to adopt a clean energy target was not unanimously agreed by the Energy Council. A National Energy Guarantee (NEG) was proposed by the Australian Government as an alternative to encourage and guide new investment in clean and low emissions technologies, ensure the security of the electricity system, and produce reliable electricity. Further, recommendation 7.2 of the Finkel Review proposed the establishment of “an Energy Security Board [ESB] to have responsibility for the implementation of the blueprint and for providing whole-of-system oversight for energy security and reliability”.¹³

Responsibility for the development of the NEG sits with the ESB. The NEG is being designed to ensure the security and reliability of supply within an emissions-constrained trajectory and with an ‘at lowest-cost requirement’. The ESB is providing advice to the Energy Council on the design of the NEG and at the time of writing is expected to finalise that advice in August 2018.

2.2 Ancillary and other services

The NEM was built on the back of Australia’s vast coal resources and the cheap electricity generated with them. Other contributors to supply throughout this period include Tasmania’s hydroelectric system, the Snowy Hydro Scheme and increasingly the use of gas for electricity generation. All these generation technologies supply electricity into the system with characteristics important to the physical security of the system. When electricity is produced by burning coal, gas or diesel or by water driving turbines, the process also supplies a range of specific services into the system. These services have not traditionally been valued or rewarded within the system as they were just ‘there’ and available, so there was no need to ensure or support them.

These services or capabilities include inertia and frequency control ancillary services (FCAS). Fast frequency response (FFR) is also an important system requirement that has been highlighted in recent outage events. The retirement of fossil fuel systems alongside

¹³<https://www.energy.gov.au/government-priorities/energy-markets/independent-review-future-security-national-electricity-market> 2017.p.30.

Australian Concentrating Solar Thermal Roadmap

the increasing penetrating of VRE creates new challenges for the system in terms of the loss of these services and capabilities.

The Finkel Review's focus on secure and reliable supply of electricity required consideration of these technology and management systems due to their capacity to ensure an overall robust system that provides a reliable supply of electricity when it is needed by customers. In addition to inertia, FCAS and FFR, the relevant technology and management systems include storage and demand management. Each must be assessed for cost effectiveness and applicability in the required location and load.

As Australia progresses through the orderly transition, no single solution is going to be that elusive 'silver bullet'. The range of options able to deliver such services needs to be investigated, analysed and trialled to inform and optimise investment and reliability outcomes. Those options include:

- The development of electricity generation projects utilising technologies that are new to Australia, such as CST, with inherent attributes that have historically contributed to the security and reliability of the system across the NEM.
- The development of energy storage projects to overcome the challenges presented by the supply and demand imbalance caused by VREs.
- The use of demand management as a low-cost strategy to reduce consumption during periods of peak demand.

The Finkel Review made several recommendations to ensure that some obligations are placed on new entrants to include these capabilities, particularly in vulnerable areas of the NEM.¹⁴

This Report also considers CST's ancillary service capabilities as part of its evaluation of the role that CST can play in the provision of emissions-free, secure and reliable electricity at low cost in Australia and particularly within the NEM.

2.3 The emergence of energy storage technologies

An important tool for managing the reliability of supply from VRE projects is energy storage. Large-scale batteries and pumped hydro energy storage (PHES) are currently in the forefront of the public's attention. For example, South Australia made international headlines in 2017 through the installation of the world's largest utility-scale lithium battery system near Jamestown to "smooth supply from a local wind farm".¹⁵ Householders are also increasingly installing battery systems to store energy from their PV systems for use outside of sunshine hours.

Further, Snowy Hydro has recently undertaken a feasibility study for Snowy 2.0, a PHES system designed to improve system security and the reliability of supply across the NEM, located within its Snowy Mountains Scheme in New South Wales. Snowy Hydro's plan is to use electricity when the price is low to pump water up to storage dams for release downhill to drive turbines when the VRE supply does not meet the demand requirement,

¹⁴ System Security recommendation, pp22-3.

¹⁵ <http://www.adelaidenow.com.au/news/south-australia/worlds-largest-lithium-battery-switched-on-near-jamestown/news-story/2c4992845ce77309d7dad0d48a2d754c>

Australian Concentrating Solar Thermal Roadmap

particularly at peak times when the price is high. Importantly, PHES also has the capability to deliver ancillary services in the same way that hydroelectricity does.

CST technology is not as well understood by the Australian public. CST captures and stores heat from the sun, and then uses that heat to produce electricity. In fact, CST behaves in an almost identical way to coal-fired power generation within the electricity supply system. Instead of burning coal to create high-temperature steam to drive a turbine, it simply uses heat from the sun to produce the same generation profile without the carbon emissions. Because the heat can be stored, it can also be extracted to generate electricity at any time, day or night. Given these attributes, CST is gaining increased international attention with over 5 GW of installed generation worldwide.

As highlighted above, storage technologies will play a critical role in ensuring the reliability of supply in response to VRE impacts and, to some degree, the loss of ancillary services as we go through the transition to a low carbon electricity supply system. Each available storage technology has differing technical capabilities and commercial drivers, and will be required across the NEM in accordance with these capabilities and drivers.

2.4 Low cost – rewarding customers

The final and perhaps most contentious issue at the centre of the Finkel blueprint recommendations is how to bring these complex and integrated matters to effect while doing so at the lowest cost. Specific technology solutions will be more appropriate across different regions of the NEM, and the optimal solution will be dependent on the problem that it is seeking to resolve. The Energy Council, the ESB and other relevant regulatory bodies are acutely aware of the importance of this issue and will continue to consider how future investment decisions should be incentivised in order to achieve the transition at lowest cost.

Up until now, CST has not attracted much attention as an option for contributing to the national energy security and reliability problem. This Report thus interrogates where in the NEM could CST's various attributes add most value to the transition, in line with the Finkel Review's four key outcomes. It does this by assessing all viable technology and system management options through an extensive economic analysis of where and at what level they can most competitively contribute.

2.5 CST as a contributor to the Finkel blueprint four key outcomes

This Report is produced to contribute to the national effort as the Energy Council and the governing bodies across the energy market system develop measures to implement the recommendations of the Finkel Review. In doing so, it also provides initial analysis to the CST industry sector, market participants and research sector. The Report reveals if and where the early projects make most sense in line with the Finkel Review outcomes, and whether there is a longer-term future for the CST sector in Australia.

As referred to consistently throughout this Report, CST is an electricity generation technology that utilises thermal energy and thus lends itself to provide system security and reliability through the inclusion of storage technology alongside the generation asset. CST technology can effectively dump energy in the form of heat into various storage media and then extract that energy at high levels of efficiency to produce

Australian Concentrating Solar Thermal Roadmap

electricity when required. The range of CST technologies, storage technologies and configurations are described in detail in ITP's report, which can be found at Appendix 1.

A meaningful analysis cannot be undertaken without an equal consideration of the range of technology options offering similar attributes that can also contribute to the four key Finkel Review outcomes.

This Report also examines the potential opportunities for Australia to gain further benefits from the contribution of CST to the energy transformation by developing domestic supply chains for the sector, providing broader spillover sector benefits to other sectors of the economy, and significant opportunities for skills development and jobs.

2.6 The Australian experience and emerging global developments

The CST projects developed in Australia up until this time include:

- The (1.5 MW_e – 36.5 MW_{th}) CHP Sundrop Farm project near Port Augusta in South Australia, Australia's largest operating glasshouse.
- The 9 MW project at Liddell in New South Wales, which operated until the turbine to which it was connected was decommissioned.
- The 44 MW_e (125 MW_{th}) Kogan Creek project in Queensland, which was not successful due to technical and contractual difficulties but which contributed valuable learnings¹⁶.
- The test field at CSIRO's Energy Flagship in Newcastle.
- Vast Solar's 1.1 MW_e pilot project at Jemalong in NSW.
- Lake Cargelligo, a 3 MW_e system using graphite storage technology now owned and being advanced by Australian company SolarStor.

Further, the South Australian Government has signed a power purchase agreement (PPA) with Solar Reserve to use energy generated and stored at its proposed 150 MW Aurora project near Port Augusta. At the time of writing this project had not reached financial close.

As discussed in detail above, up until this time the major incentives to develop new renewable energy projects in Australia have focussed on the cost of energy rather than on the value of energy to the system. In markets where the value of energy supplied is incentivised, not just the cost of generation, CST systems are providing economic and system stability benefits today. These markets exist in parts of the USA, South Africa, Israel and in Europe.

ITP's Report at Appendix 1 examines a selection of the world's successful CST projects and their drivers. This examination shows that CST's capabilities or attributes create value that can be identified, costed and incentivised to deliver secure and reliable renewable generation. This value opportunity has clear implications for countries with a good solar resource such as Australia and suggests that an incentive structure, which

¹⁶ <https://arena.gov.au/assets/2016/09/Kogan-Creek-Solar-Boost-Final-Report.pdf>

Australian Concentrating Solar Thermal Roadmap

provides value for attributes, could deliver significant benefits to Australia's energy system in line with the Finkel Review outcomes.

2.7 Process heat

Due to the nature of CST infrastructure and its applicability for the production of heat and electricity, this Report will also comment on the potential of CST to supply energy in the form of heat for a range of other applications. These applications are not currently incentivised through any national scheme such as the RET, yet they can make a substantial contribution to offsetting the use of electricity in a range of industrial heating applications. Importantly, they could also offer further revenue sources for CST developers to assist in incentivising deployment, thus reducing the overall costs of energy supply. These applications also open up the opportunity for the combined supply of electricity and heat to energy-intensive processing industries across Australia's regions, which have not previously been considered at any depth.

While this Report touches on the process heat implications around CHP systems, the direct use of thermal energy is *not* its focus. CHP is mentioned because of its interconnectedness with electricity and additional potential value steam.

The application of solar thermal energy to industrial processes has wide potential and could have a major positive impact on emissions from industries such as minerals processing and the production of 'solar fuels'. The latter are fuels that are created by effectively embedding solar energy in chemicals for later use. An example of this is a solar hydrogen production process where concentrated solar energy is used to produce hydrogen from water at high efficiencies.

ARENA is supporting detailed analyses of the potential role of renewable energy in hydrogen production and for mineral and metal resource processing projects through means other than this Report.

2.8 Research

The Australian public has invested tens of millions of dollars in CST R&D in Australia over recent decades. This investment culminated in the 2012 establishment of the Australian Solar Thermal Research Institute (ASTRI), which brought together the CSIRO and six other leading Australian CST research institutions. As a result, Australia is now placed at the forefront of global research efforts to develop CST technology.

A major research challenge for CST moving forward is the development of a reliable and cost-effective high temperature pathway. The jump in current system temperatures from around 560°C to 710°C will accommodate more efficient supercritical CO₂ turbines in the future and will increase system efficiency by over 20%. This will produce significant cost reductions for CST technology. The major work in this area is being undertaken by the United States' Gen3 Program and by researchers in Europe.

In recognition of ASTRI's leading edge capabilities, these US and European institutions at the forefront of global CST development have sought to collaborate with ASTRI on higher temperature CST pathways. This collaboration includes a stronger focus on technology demonstration, pilot studies and closer engagement with industry on commercialisation

Australian Concentrating Solar Thermal Roadmap

pathways. This approach is critical to increasing the rate of global and domestic uptake of CST technology.

This Report highlights the role that ASTRI can play in the commercialisation efforts and development of a sustainable CST industry in Australia over the coming years.

2.9 Roadmap approach and consequential direction

The major impediment to development of a CST sector in Australia has been its higher cost at the point of generation without consideration of, or reward for, the additional value that it can provide. The analysis undertaken for this Report indicates that CST makes an important contribution to the four outcomes of the Finkel Review and, despite its higher LCoE relative to cheaper VREs, increasingly will do so at lowest cost over the next two decades.

This Report therefore focuses on the initial development of CST projects in Australian regions where its combined attributes add most value to the national supply system. The aim is to establish a pathway that delivers the least-cost, lowest-risk value to the system over the short term and, in doing so, deliver more cost-effective longer-term outcomes.

The Report therefore provides a Roadmap that includes clear, innovative and rational incentives that together provide a pathway for the development of the CST sector in Australia over the short, medium and longer term.

The approach of the modelling and analysis undertaken for this Report, which has uncovered and quantified this value, has been to:

1. Identify the current costs and cost curve predictions for the delivery of energy from CST systems.
2. Identify the level of reliable electricity required within the transmission and distribution networks.
3. Identify and value the benefits of CST to the national energy supply system and unpack the 'value stack' to identify individual value components.
4. Explore where value can be captured, with attention to those regions where value is highest, and explore mechanisms to transfer sufficient levels of this value to the developer/generator to provide an adequate return on capital for early projects.
5. Establish the NPV of CST systems in various scenarios.
6. Identify opportunities for Australian industry across areas that are not currently involved in CST to engage with and expand into this area.
7. Model the direct and indirect economic activity that will result from CST deployment under the two mid-range scenarios, being the Base Case and the No Regrets Case.
8. Identify a development pathway that could see a commercially sustainable CST sector in Australia.
9. Identify initiatives that would incentivise early investment in regions where the value is highest to enable ongoing R&D activities, learnings and cost reduction activities through deployment, to facilitate the effective and sustainable integration of CST into the Australian electricity and energy system.

Australian Concentrating Solar Thermal Roadmap

The Roadmap builds on previous Australian and international work that has concentrated on the current and future costs of CST. It proposes recommendations that could reduce costs and transfer value within the market to demonstrate how to make CST projects become attractive to commercial investors. The combined recommendations comprise a strategy that opens up a pathway for the development of a range of CST applications, leading to larger-scale electricity generation projects with storage connected across the transmission network.

2.10 Policy landscape

It should be noted that, at the time of writing, the national energy policy landscape was in a highly fluid state. Processes underway and due to be finalised later this year include:

- Consideration of AEMO's renewable energy zones in the context of the recently released Integrated System Plan
- further work on responses to the recommendations to the Finkel Review
- the final design of the NEG.

2.11 Jargon

CST: As discussed above, CST can be used to deliver electricity and/or thermal energy, depending on energy requirements and the relevant application. Over time, various names have evolved for the range of applications but they are not always used in a standard way. For simplicity, mentions of concentrating solar thermal, concentrating solar thermal power, and concentrating solar power are references to the use of CST to produce electricity.

Fringe-of-grid and off-grid systems: These play an important role in this Report and are consequential to the Roadmap as the modelling identifies them as areas where early deployment value can be realised.

Fringe-of-grid systems exist within a distribution network at the fringe, or near the fringe of that grid. Their development adds value in one or more of the following areas by:

- reducing the cost of current or future investment in the network infrastructure by avoiding the need to upgrade substations in these areas
- avoiding the cost of current or future investment in the network to the outer areas by extending or upgrading poles and wires infrastructure in the network
- improving system security and supply reliability by providing energy and ancillary services back in to the network from the fringes
- reducing overall network losses by locating generation close to remote demand centres.

Once fringe-of-grid systems based on CST effectively become connected microgrids and demonstrate reliability of supply, they *may* be disconnected from the network.

Off-grid systems are considered as systems deployed off the grid for towns, small communities and mining operations and, as indicated above, some fringe-of-grid systems may become off-grid systems at some stage in the future.

Australian Concentrating Solar Thermal Roadmap

Large-scale CST systems: These transmission network-connected systems are typically 100 MW or more but can be as small as 30 MW. They will typically be tower/heliostat based systems.

Smaller CST systems: These are typically in the 5-30 MW range but may be as large as 50 MW. They typically operate at lower temperatures and efficiency than large systems and, today, are typically trough-based systems rather than heliostats with towers

Small systems: These may be CHP systems that sit behind the meter delivering both heat and electricity to a specific user. They may also provide only heat and will normally be less than 5 MW.

3 Concentrating solar thermal technology

3.1 Introduction

Concentrating solar thermal systems use arrays (or fields) of mirrors to focus solar energy onto high temperature receivers that capture the energy and use it to drive electricity generators or provide heat for industrial processes. This Report focuses on CST for electricity generation while also acknowledging that there is significant potential for CHP systems that can deliver both electricity and heat to meet the needs of specific energy-intensive businesses and institutions.

CST differs from a solar PV system by:

- using heat to drive traditional thermal generators rather than photons in a semiconductor
- storing thermal energy for later use, allowing it to produce dispatchable electricity
- behaving like a traditional thermal power station with a rotating mechanism providing inertia, frequency control, increased network stability and reliable or dispatchable electricity.

CST is an emerging technology in Australia. Commercial deployment is advancing around the world with 5 GW now either in operation or under construction. This is still a relatively low level of deployment on a global scale. However there is a high probability and increasing evidence that major technical and economic advances are continuing as CST matures, and that this is leading to ongoing cost reductions.

The sector is attracting growing interest around the world due to the increased understanding of the need for new dispatchable generation with reduced emissions and the realisation that CST's capabilities can deliver these benefits. This interest is expressed through significant government sponsored and increasingly coordinated research efforts underway in the US, Europe and other parts of the world including Australia.

CST effectively replaces fossil fuels with solar energy to drive traditional thermal turbines. In many ways CST is the zero-emission version of traditional thermal (that is, coal- and gas-fired) electricity generation. Furthermore, the storage of thermal energy using CST enables electricity to be produced at any time of day or night. This noted, there are both practical and economic limits to how much and how long energy can be stored.

Australian Concentrating Solar Thermal Roadmap

Key factors in the accelerated emergence of CST include:

- advancement in thermal energy storage technologies
- rapidly growing share of VRE
- need for dispatchable synchronous generation with inherent inertia to be distributed within electricity networks to enable the growth of VRE uptake, particularly as the aging fossil-fuel based generator fleet retires
- decreasing CST costs due to its growing deployment and resultant learning curve
- increasing maturity and understanding of CST technologies
- advances in more efficient, high temperature turbines with the potential to significantly improve CST system performance and economics.

CST requires strong direct radiation to generate electricity or store heat for later generation. It is also best suited to the vast areas of arid countryside in Australia where there is access to electricity transmission infrastructure or local population centres.

ITP Thermal was commissioned to provide a detailed analysis of CST technology to inform this Report, including the technology's current and projected capabilities. More detail on CST and its improving performance can be found in Appendix 1.

3.2 History of CST in Australia

Up until this time, CST has not been widely deployed in Australia and has produced mixed results. Some semi-commercial systems have been abandoned, due in part to unrelated external events. However other projects are emerging as technically and commercially successful, or with the potential to provide technology breakthroughs leading to significant cost reductions.

The Australian experience with CST projects is predominantly in smaller demonstration projects. The most significant previous effort to introduce utility-scale CST systems in Australia was the Solar Flagships program announced by the Australian Government in May 2009. Round 1 of the program targeted a total of 400 MW_e through the development of one CST and one PV project. The successful CST proposal was the Wind Prospect/Areva Solar Dawn proposal for a 250 MW system near Chinchilla in Queensland. The Australian Government was to contribute \$464 million for the project, which was worth an estimated \$1.2 billion. Ultimately this project did not reach financial close or proceed. In retrospect, there are significant lessons to be learnt from elements of the project, including:

- the attempt to procure a single project bigger than any that had been built globally at that time
- awarding the project largely on cost to a technology supplier without a significant track record
- failing to ensure an off-take agreement would be achieved as part of the program requirements.

Importantly, a number of Australian companies have since made real progress with CST technologies either under development or planned for development, but they are yet to move into commercial operation. These include:

Australian Concentrating Solar Thermal Roadmap

- Vast Solar, which with assistance from ARENA to establish a proof-of-concept system at Jemalong in NSW, is now preparing to establish a 30 MW fully operational system that is intended to become a building block for modular scalable systems in the future at significantly lower cost than more conventional systems. <http://www.vastsolar.com/>
- SolaStor, which has developed a unique graphite-based thermal storage system. After some small-scale research and testing in NSW, the company is developing potential projects in Australia and overseas. <http://solastor.com.au/>
- Terrajoule, which has origins in Australia, moved to the US, and is now heading “home” with a plan to deploy small (but scalable) CST systems. This will be achieved by integrating an existing trough-based solar collection system with traditional steam engines in fringe-of-grid and off-grid locations. <http://www.terrajoulecorp.com/>
- HeliostatSA, which was formed in the aftermath of Australia’s reduced participation in automotive manufacture. The company is planning to apply Australian manufacturing skills and systems from the automotive sector with control systems developed by the CSIRO through ASTRI to provide low-cost and high quality heliostat systems to the sector. (<https://heliostat.com.au/>)
- The ANU’s “Big Dish” system, which was developed within the university and is now paused after a couple of commercialisation attempts.

There is one CST system currently operating in Australia, which is largely focused on supplying heat for the desalination of water at Sundrop Farms. The operation is Australia’s largest glasshouse producer of tomatoes, providing 15% of the product sold by Coles Supermarkets. This CST system uses a heliostat field and tower with a capacity of 36 MW_{th}. It produces steam, which is partly used for 1 MW_e of power generation but otherwise directed to the desalination plant.

Throughout the course of producing this Report, several companies provided input on projects they are developing along similar lines to the one at Sundrop Farms. The Sundrop Farms project provides a clear example of how a smaller, bespoke CST system can operate in a commercially successful manner in bespoke locations, due to the diverse sources of income derived from multiple uses of the solar energy collected on site.

3.3 CST globally

Around 5 GW of CST systems have been deployed globally. Earlier projects received support from some European governments through feed in tariffs (FITs), and in the US through a combination of tax credits, government-supported debt facilities and a highly competitive electricity retail sector.

This early support is now seeing CST expand into emerging economy markets, where the demand for energy is increasing and CST is competing with new infrastructure rather than with the marginal generation costs from older, heavily depreciated generation fleets.

Early development occurred in the US and Spain. In more recent years, CST plants have also been completed in Morocco, South Africa, India and UAE. Additional multi-

Australian Concentrating Solar Thermal Roadmap

megawatt projects are under construction or under development in China, Chile, Morocco, Israel and Saudi Arabia.

The current 5.1 GW_e of installed capacity in CST is predominantly made up of around 64 plants that are 50 MW_e or larger. This constitutes over 90% of the installed capacity, with the remainder comprising about 32 smaller pilot type projects. Approximately 40% of existing plants and most new plants also incorporate thermal energy storage. Thermal storage based on tanks of molten salt (potassium and sodium nitrate mixtures) has become the current industry standard and is used exclusively on large commercially-operated plants.

While the increasing maturity of the CST sector has led to a narrowing of the focus on technologies for advancement, smaller-scale storage technologies are more varied and include water, sand, concrete, graphite and rocks.

The relative youth of the CST sector means there are also opportunities for new storage approaches to break through. SolarStor's graphite storage system, Vast Solar's sodium heat transfer and molten salt storage approach, and Terrajoule's innovative re-imagining of a traditional steam engine, all have the potential to carve out a space in the global dispatchable renewable energy market.

3.4 Economics of CST in Australia today

The modelling shows that the economics of CST generation today is not competitive with VRE generation from wind and PV or the existing fossil fuel fleet. CST however:

- provides additional value to the network over non-schedulable generators and would be more competitive in a range of locations if it could capture this value from the market
- is on track to become cost-competitive with wind or PV paired with battery storage, as well as providing additional value to these systems as a synchronous generator
- is competitive with PHES systems
- is expected to outperform both batteries and PHES within the next decade
- will compete with, and outperform, new combined cycle gas turbine (CCGT) systems by 2030 as CST costs decline without being tethered to local or international gas prices.

3.5 CST and electricity networks

The delivery of electricity within the NEM is achieved using three types of 'poles and wires':

1. interconnectors that provide high-volume connections between parts of the network, such as between Victoria and NSW or South Australia
2. transmission networks, which are the electricity highways that deliver goods (electricity) in bulk form to population and other demand centres
3. distribution networks that can be likened to suburban roads delivering the goods directly to consumers.

Australian Concentrating Solar Thermal Roadmap

Large-scale transmission-connected CST systems have come to define the public's perception of the CST sector. In part, this is because large systems have been built on the basis that they are more efficient and therefore cheaper at larger scale. In part, it is also because of the increasing uptake and therefore visibility of CST systems in emerging economies where large centralised generators are required to supply the growing need for energy in the most viable combination of cost and emissions sensitivity.

However the Australian scenario is different. Australia has sufficient electricity to meet its current needs. The impetus behind our need for new generation is to replace an aging fossil-fuelled generation fleet along with the additional benefits they offer to the system, and reduce our emissions so that we can meet our international obligations under the Paris Accord. In addition, a quarter of Australia's population is spread over a vast landscape. Transmission and distribution networks carry electricity over enormous distances incurring both growing costs in extensions and maintenance and large losses due to the often vast distances between generators and consumers.

The nature of Australia's electricity network and widely distributed demand is in line with its widespread population. This means that the transition to a secure, reliable, cost-effective and low-carbon energy system is likely to see a significant part of the network being serviced by smaller, more scalable and distributed generation systems as our existing and aging generating fleet is retired.

CST has the capability to provide scalable, reliable, emissions-free dispatchable generation. Its scalability enables the development of CST within the distribution network and location closer to consumers, thereby reducing network losses and the load on both transmission and distribution networks.

Small-scale CST also presents the opportunity to power some off-grid townships or industrial enterprises such as mining operations, and enable some towns to come off the grid altogether while reducing costs and increasing energy security and reliability.

3.6 Large-scale CST

Large-scale CST systems have typically been the major development focus for the international CST sector. This is because of their importance in lowering emissions and providing large volumes of dispatchable energy. The leading CST technology for large systems with storage is based on molten salt as a heat transfer and storage medium.

Large-scale CST infrastructure is well suited to electricity systems that need to provide increased capacity to respond to rapidly growing demand, particularly if there is existing or new transmission capacity to carry the large volumes of energy from the generating source to demand centres, primarily cities.

Most of the 5 GW of CST's global capacity is in larger systems, which are in the 100-150 MW range. In the Australian context, these systems are still a fraction of the size of our typical coal-fired power stations.

While Australia currently has little demand for new, large generation infrastructure, this will change over the next 10 to 20 years as the aging fossil fuel generators exit the market. The modelling undertaken for this Report indicates that CST is expected to be the most competitive technology to replace retiring generation from 2031 through to

Australian Concentrating Solar Thermal Roadmap

2040 and beyond, due to its combination of dispatchability and emissions free performance. This competitiveness becomes even greater if emission reduction targets are strengthened.

Australia currently has one large-scale CST project planned for deployment, near Port Augusta in South Australia. This project was announced in 2017 and at the time of writing is currently seeking approvals and funding to commence construction. Solar Reserve, a major US-based developer of large-scale CST technology and projects, is developing the 150 MW project. The modelling for this Roadmap has assumed the development of a CST project of this size will go ahead in this region.

3.7 Smaller-scale CST

3.7.1 Overview

Smaller CST systems are typically less efficient than larger systems primarily because the efficiency of turbines, whether they are heated by coal, gas or solar energy, is lower at smaller scale. Maximum efficiency is generally considered to be reached in systems over 100 MW. This may change in the future if current initiatives to develop 'supercritical CO₂' turbines deliver scalable high-efficiency turbines for all thermal generation technologies. Despite their lower efficiency, smaller systems can still be economical due to a number of factors:

- They typically use more mature technology than larger systems and thereby ameliorate some of their lower efficiency with lower component costs.
- They are typically located in areas of the grid where they can have a significant positive impact on network behaviour and costs. If they were rewarded for this by receiving the benefit of any avoided network investments, this would see them enter the network in a significant number of locations.

There are at least four potential scenarios for the development of smaller CST systems in Australia including:

1. distribution-connected CST systems that are smaller than 30 MW, typically in the 10-30 MW range selling all their output via the grid
2. off-grid power systems where CST, combined with other generation technologies such as solar PV and diesel backup, can be used to meet all the electricity needs of a community or enterprise
3. behind-the-meter CHP systems where some of the solar energy collected is used to generate electricity and some is used as heat to drive industrial applications such as food processing or production
4. behind-the-meter systems that are located beside an industrial-scale consumer and provide the majority of the electricity they produce directly to that consumer. Any excess power produced can be exported to the market via the grid.

Australian Concentrating Solar Thermal Roadmap

3.7.2 Fringe-of-grid distribution connected CST

The following is an *example* of a potential distribution-connected CST system that could be installed in several locations within one of the NEM's distribution networks.

Technology:

- located in regional Queensland
- 30 MW (net) power block with a traditional steam turbine
- molten salt storage system providing the equivalent of 7-10 hours, depending on the heliostat field size, of storage at full (30 MW) output without sunshine, or longer at a lower capacity
- 130-155 hectare heliostat based solar energy collection field
- 100-130 30 metre towers.

Performance:

- annual production of 130-150 GWh
- capacity factor of 46-53%
- heliostat field is configured to enable energy to be stored and exported concurrently. This enables energy to be dispatched during sunshine hours as well as into regular evening periods of peak demand periods (and other non-sunshine hour peaks) when supply is tightest, wholesale prices and stress on networks is high
- able to respond to market needs by dispatching when called on to do so, or when the supply and demand balance produces high wholesale prices.

Commercial arrangements:

- PPA with a retailer that recognises and rewards the value of dispatchability by rewarding time of day dispatch
- transfer of the avoided network costs to the generator, paid on a per MWh basis, as per the No Regrets Case.

3.7.3 Behind-the-meter CST

Behind-the-meter systems are similar to the distribution-connected systems, but rather than being directly connected to the grid they are connected behind a meter inside the consumer's property. They would typically range from as small as 1 or 2 MW to perhaps 10 MW of electricity generation and may also supply some heat (see Combined heat and power at 3.7.5). Even smaller systems may be used to supply low temperature process heat for commercial consumers (see Small, low temperature heat systems at 3.7.6).

The system may be owned and operated by the consumer to reduce the amount of electricity bought from a retailer via the grid. Alternatively, an independent power producer (IPP) may own the system, bypassing the retailer, and selling the energy produced to the consumer and at a lower cost than could be provided by a retailer.

The behind-the-meter CST system could also make it possible for the consumer to disconnect from the grid. This could result in the consumer not only reducing electricity costs but also reducing or eliminating the consumer's network charges, which make up approximately one third of their current energy bills.

Australian Concentrating Solar Thermal Roadmap

Physically, the electricity network and market would not see the CST generator itself, but would instead see a reduction in demand at that location and a reduction in stress on the network.

The following is an *example* of a potential behind-the-meter grid-connected CST system that could be installed in several locations within one of the NEM's distribution networks.

Technology:

- located in NW Victoria
- 2 MW (nominal) power block with a traditional steam engine
- water-based thermal energy storage system providing the equivalent of 12 MWh (electrical) of storage, which could run for 6 hours at full capacity without sunshine or longer at a lower capacity
- 8 hectare trough-based solar energy collection field.

Performance:

- annual production of 3.8 GWh
- capacity factor of 22%;
- predominantly dispatching energy in line with the consumer's demand
- storing excess thermal energy not required to meet the consumer's instantaneous demand for later use to dispatch electricity to the consumer when it is required
- able to dispatch excess energy to the wholesale spot market in times of peak demand to maximise the return via the consumer's existing grid connection.

Commercial arrangements:

- PPA with a corporate off-taker to take all output from the system whenever the PPA price is higher than the wholesale spot price. When the spot price is higher than the PPA tariff, output from the system will be sold at spot and the off-taker will purchase from their retailer at an agreed tariff
- project will provide the off-taker with approximately 40% of their total annual demand
- financial compensation from the market operator for the network savings being delivered by the generator, paid on a per MWh basis.

3.7.4 Off-grid CST systems

Off-grid systems typically support a single consumer, for example a remote mine, town or community where the cost of maintaining a grid connection is prohibitive. When it supports a community, an off-grid system is usually referred to as a micro or mini grid.

Electricity grids typically have multiple generators spread over multiple locations and use multiple technologies. These diverse attributes reduce the risk of single points of failure, a problem that we have experienced in Australia. These problems are most often 'poles and wires' related and only affect sub-sections of the grid.

Microgrid users and generators have a key characteristic that separates them from grid-connected users and generators; there is no ability to draw power from anywhere else should there be a system failure or resource shortage. This means that all the resilience

Australian Concentrating Solar Thermal Roadmap

required to run an electricity system must be within the microgrid or the users must accept lower reliability.

The consideration of the potential use of CST in off-grid environments required an analysis of the need for resilience and redundancy and the need to meet reliability standards. Energeia's modelling pulled together configurations that could meet AEMO reliability standards while still being economical.

Energeia's model assumes that any network savings are provided to the generator if the system is a fringe-of-grid location that gets moved to off-grid. Existing off-grid locations are already avoiding network costs so a CST system would be competing with local generation costs that are significantly higher than they are in large networks where reliability and stability costs are spread over many generators.

Energeia's model builds a generation and storage mix that will not only enable the reliability standard to be met, but also provide the best economic configuration with diverse components much like the NEM grid. The typical configuration includes:

- CST system with storage for the majority of production
- PV with a small amount of battery storage for smoothing
- diesel system capable of meeting peak demand, should it be needed at 100% redundancy.

The PV system produces the cheapest electricity during sunshine hours, and the CST system meets demand when the PV system is not generating or when demand exceeds the capacity of the PV system. Diesel is included as a backup to meet demand when there is a lack of sunshine and the storage system is exhausted.

The diesel component adds significantly to the CAPEX of the system but the combined solar PV/battery/CST system would supply 97% of annual demand. The diesel system is used exclusively as backup for 3% of the time.

Configurations of off-grid systems that meet AEMO's reliability standards are highly bespoke. The elements of the system are described above but there is no such thing as a 'typical' configuration therefore no example is included here.

3.7.5 Combined heat and power

The Sundrop Farms project in South Australia has demonstrated the commercial opportunity presented by CHP in Australia but little has been published about it, which has limited the learnings.

Throughout the course of the stakeholder consultation undertaken for this Report, it was evident that there are a number of CST projects under development including both CHP and projects that are solely thermal. In both cases, the non-electrical component of the energy supplied will be used to displace gas. The latter is of growing interest due to recent increases in gas costs and forecasts that this trend will continue.

Food production or processing projects under development range in size from 6 to 50 MW_{th}, some being solely for thermal use, others split between electricity production and heat. The project team viewed eight projects, all at various stages of development. Cost

Australian Concentrating Solar Thermal Roadmap

savings on gas and electricity charges have the potential to be up to 35%, though this varies significantly by project depending on:

- volume and price of current electricity and gas being consumed
- level of solar resource at the location
- costs of project unique customisation/integration in some cases.

The typical commercial arrangement required by the potential user of the energy is an energy purchase agreement (EPA) for both heat and electricity, as energy production is not the core business of any of the potential clients. This means that the CST system is likely to be owned and operated by a third party.

It would appear the main barrier to financial close on the projects is confidence in the technology. While potential clients are not directly investing in the technology and therefore would not carry technology related risk, the integration process presents potential disruption and operational risk to them.

Throughout the investigations and consultations that were undertaken for this Report, JHA identified a number of process heat projects for minerals or chemicals processing that are currently under development ranging from 95 MW_{th} to 575 MW_{th}.

All the CHP projects under development that have been reviewed by JHA were behind-the-meter systems and all incorporated parabolic trough technology.

JHA can only provide information on these projects in a summarised and unidentified manner due to the sensitive nature of the project development stages.

Australian Concentrating Solar Thermal Roadmap

4 Energy market economic analysis

4.1 Background

The key objective of the modelling undertaken to interrogate the case for CST in Australia is the identification of the potential sources of value from CST generation and storage across a range of small and large-scale market segments, and off-grid and grid-connected sub-segments.

4.2 Scope and approach

Energeia developed, configured and ran its whole-of-power system simulation platform (uSim) to model the CST value streams out to 2040 including potential CST market sizing across the following four different market segments:

- **Large-scale:** Transmission-connected CST acting as large-scale renewable energy generation with storage, offering dispatchable electricity and ancillary services, primarily frequency regulation, to the market.
- **Smaller-scale:** Distribution-connected communities in areas where the network faces a significant investment in infrastructure upgrades due to current or emerging cost-to-serve issues, and where dispatchable local CST systems can avoid network augmentation. In many cases this could enable separation from the grid and provide the least cost, best reliability solution.

Note that over time, the improving economics of CST combined with fossil fuel based exits from the market will see CST systems being more widely deployed in the distribution network.

- **Off-grid customers:** Large remote customers who are looking to reduce their electricity costs and are currently using diesel, or diesel and solar PV.
- **Behind-the-meter systems:** Systems where energy is generated for specific commercial and industrial consumers and connected within the consumer's premises rather than to the grid are also important market segments.

These market sub-segments were combined into four different scenarios incorporating assumptions that considered the interaction between small-scale market development opportunities and the different rates of deployment of large-scale CST based on global rates of cost decline.

4.3 Assumptions

Current CST system costs were assessed by ITP based on information obtained through an ARENA CST Request for Information undertaken in 2017, as well as internationally available information. CST learning curves were derived from historical cost data and through information on global CST deployments. The learning curves were compared with those derived by the US DoE and German DLR, and were considered to be conservative. Learning curves for all other viable generation and storage technologies were based on published data.

Australian Concentrating Solar Thermal Roadmap

The modelling addresses two separate scales of CST systems (large in the transmission networks and smaller in distribution networks). In order to recognise that there are generally cost benefits from scale, the modelling assumes that the CAPEX of smaller systems in the distribution network is 50% higher (on a per MW basis) than large systems. Both systems attract the same learning rate however. The authors feel this loading supports both the reality of scale versus cost, and the fact that there is more risk in the cost curve for earlier deployments.

The following questions were examined through the modelling:

- **Low Case:** What is the uptake of large-scale CST in Australia if global deployment is slower than forecast and learning rates are slower than expected but other assumptions are the same as the Base Case?
- **Base Case (mid-range deployment):** What is the uptake of large-scale CST in Australia given the most likely case for learning rates, capital costs and global deployment, and rates without material changes to current policies or targets?
- **No Regrets (mid-range deployment with no- or low-cost measures):** How would the Base Case change if targeted interventions were made to unlock the value that CST technology provides to the energy system, to encourage the development of small-scale CST in various sub-segments of the distribution network in addition to the uptake of large-scale systems in the transmission network?
- **High Case:** What would be the net uptake of CST systems if faster global deployment of CST were achieved, resulting in faster learning rates and steeper cost declines in addition to the No Regrets recommendations?

4.4 Modelling results

The modelling shows the following:

- Under the Base Case (BaU), CST is not yet competitive with alternative sources of dispatchable generation and will not enter the market until 2031, but provides net savings to the market when it does enter totalling \$2.3bn (2018\$) by 2040.
- Under the No Regrets Case, CST will be competitive in selective locations within the distribution network by 2022 if it has access to the value of the savings it delivers within the network. This would see some 1.14 GW of CST enter the market, almost all in regional locations, with no negative impact on customer bills whilst simultaneously providing improved network stability and emissions reductions. Net savings to the market would total \$3.4 billion by 2040, of which \$1.1 billion would flow through to off-grid customers / communities.
- Current federal and state-based emissions targets will be met with the Base Case or better. Higher targets or incentives to reduce emissions would see CST entering the large-scale generation market earlier as emissions targets and incentives will change the pace of coal retirements.
- The No Regrets Case provides Australia with the ability to economically respond to changes in future emissions reduction targets from global climate initiatives and agreements at no net cost to the economy. CST becomes an even more

Australian Concentrating Solar Thermal Roadmap

important technology for a low-cost outcome under more stringent emissions reduction targets.

- The Base, No-Regrets and High cases all meet current reliability standards.
- Existing ancillary service rewards are insufficient to provide incentives for new CST generators to enter the market or to materially change existing generator behaviour.
- CST will economically outperform both PHES and PV or wind with battery storage within the next few years.

4.4.1 Market sizing

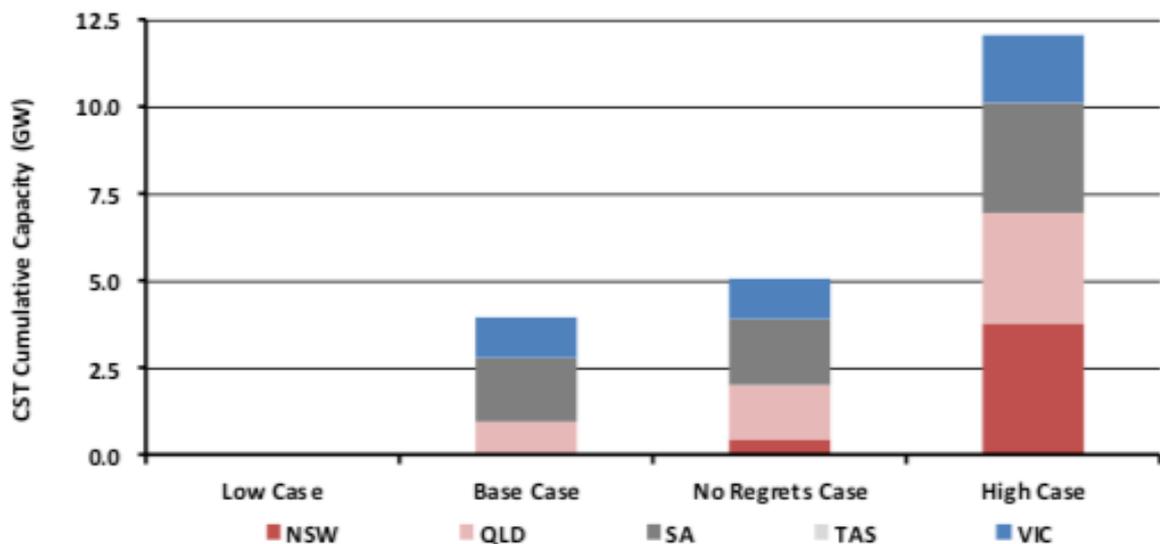
Figure 1 shows the cumulative CST uptake capacity across the modelled period through to 2040 under all four cases. It also includes information on uptake capacity by the states.

Under the Base Case, CST uptake is 3.94 GW to 2040, all in large plants connected to the transmission network. Most of the uptake occurs in South Australia, followed by Victoria and Queensland.

Under the No Regrets Case, an additional 1.14 GW of CST will enter from 2022 in the distribution network if targeted interventions to enable the deployment of CST in the fringe-of-grid are encouraged. Under this case most uptake occurs in South Australia and Queensland. NSW also enters the picture with off-grid uptake.

Under the High Case there is a total of 12.1 GW of CST uptake to 2040. NSW, followed by South Australia and Queensland account for the most uptake.

Figure 1 – Cumulative CST uptake (GW) to 2040



Source: Energeia modelling

Australian Concentrating Solar Thermal Roadmap

4.4.2 Deployment timing

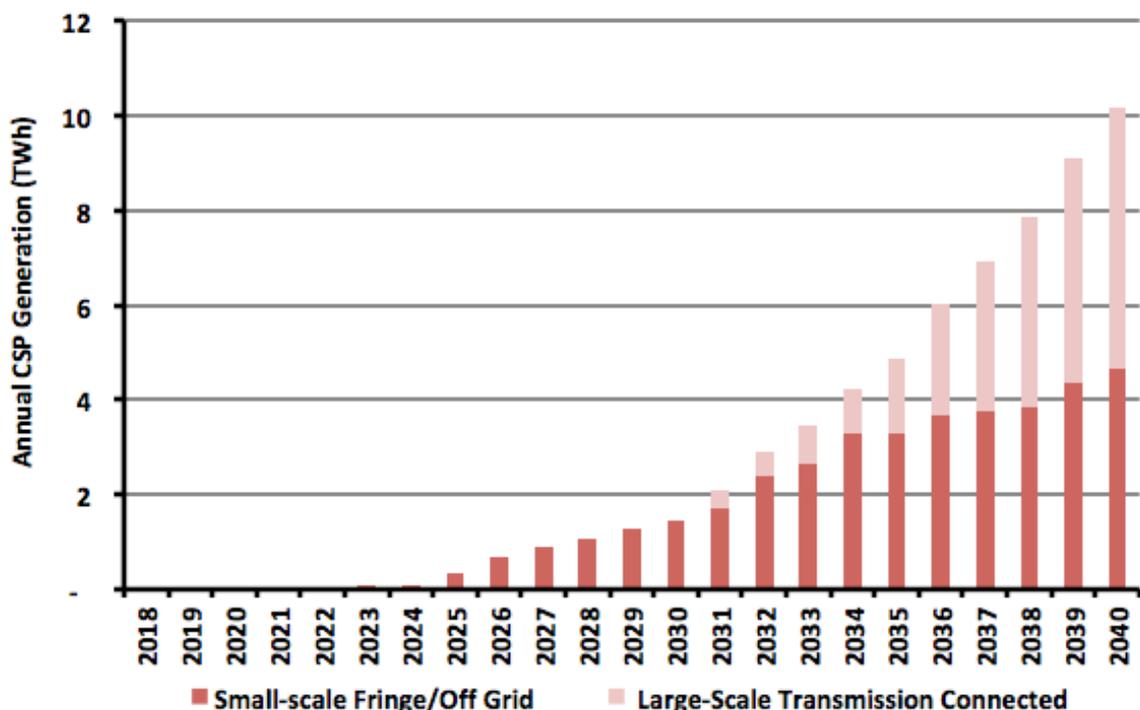
Under the Base Case, deployment does not commence until 2031 and is restricted to large systems in the transmission network. This is because there is already sufficient dispatchable capacity in the system, and new entrants prior to 2031 such as rooftop PV will be at a lower cost than CST. CST entry will be driven by existing coal generator exits. Initially, CCGT will replace coal but by 2031 CST becomes more cost competitive than CCGT and will enter due to CST’s zero emissions profile.

Under the No Regrets Case, smaller CST systems enter the distribution network where they can create network cost savings by avoiding enhancements and incremental maintenance costs. If these savings are transferred to the generator, smaller CST systems enter the network where and when they can access the value of the savings they produce to the network without adversely impacting on customer bills.

The analysis of the modelling of uptake by market segment and sub-segment reveals that the small-scale market applications are taken up in the early 2020s, between 5 and 10 years earlier than the large-scale markets.

The High Case reflects potential cost savings if global deployment, and therefore learning benefits, is achieved faster than the Base or No Regrets Cases assume.

Figure 2: CSP generation by year – No Regrets Case



Source: Energeia modelling

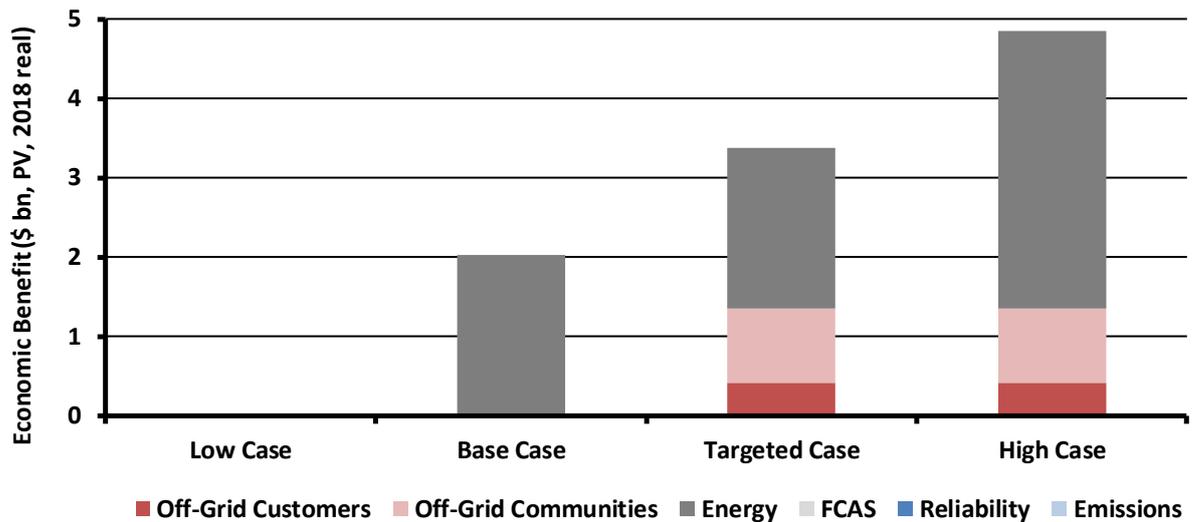
4.4.3 Customer bill savings

In the Base Case, CST delivers \$2.0 billion in customer bill savings on a present value basis through 2040. All this value is in lower energy costs, which will be delivered through customer bill savings across the NEM.

Australian Concentrating Solar Thermal Roadmap

Under the No Regrets Case the economic benefit increases to \$3.4 billion. This Case assumes the value of network savings is transferred to small-system generators in the distribution network. \$2 billion will flow through to consumers through lower energy costs, and \$1.4 billion will flow through to off-grid communities and customers.

Figure 3 – Value stack by scenario (Present Value, \$ bn, real 2018, compared to no CST) out to 2040



Source: Energeia modelling

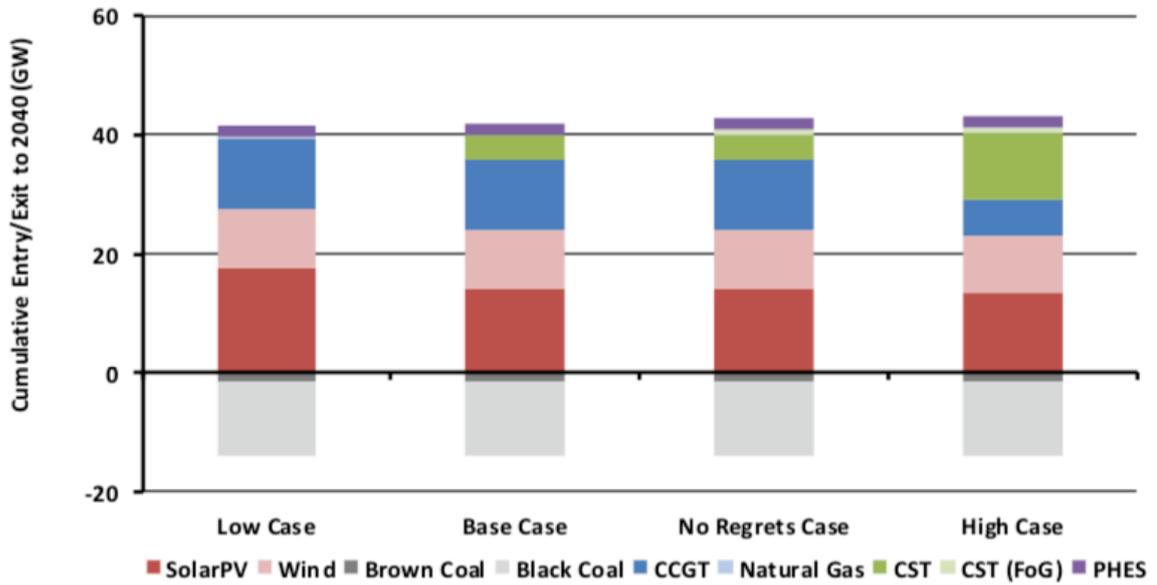
4.4.4 Entries and exits

Analysis of cumulative entry and exit of generation capacity in the period to 2040, as displayed in Figure 3, resulted in the following observations:

- Over 12 GW of coal exits and price declines in large-scale renewable technologies will contribute to over 40 GW of new generator entry in all scenarios.
- In the Low Case, there is no entry of CST generation. Instead its role is taken by new entry of solar PV and OCGT generators. However, this generation mix results in a higher cost to consumers, delivered through higher customer bills.
- The Base Case shows 40 GW of new generation out to 2040 comprised mainly of solar PV and CCGT with some wind. There is small amount of PHES and approximately 4 GW of CST has entered, primarily replacing some PV and new gas generation.
- The No Regrets Case has an additional 1.14 GW of fringe-of-grid CST entering as a direct replacement for what otherwise would have been new gas generation.
- The High Case shows the highest build of CST (12 GW) out of the three scenarios. Most of this new CST generation replaces what would have been new gas generation (i.e. there is significantly less build of CCGT generators compared to the baseline).

Australian Concentrating Solar Thermal Roadmap

Figure 4 – Net entry/exit of generation and storage (Cumulative, 2018-2040)



Source: Energeia modelling

Note: Natural gas = Open cycle gas turbines

Australian Concentrating Solar Thermal Roadmap

5 Capturing value

5.1 Modelling scenarios – Justifying a Roadmap

As described above, Energeia ran four scenarios to interrogate the value of CST to the NEM and off-grid areas (in NEM states) out to 2040. These scenarios, the assumptions they incorporated and the full results are provided in Attachment 2.

The four scenarios, previously described in more detail in Chapter 4 are:

1. Low Case
2. Base Case
3. No Regrets Case
4. High Case

The modelling has established that CST delivers significant value to the electricity market and its consumers across scenarios 2 to 4 and that this value will translate to reductions in customer bills. The analysis examining the value and the timing of the entry for CST systems across both the transmission network and the distribution network provides a clear, logical and cost-effective pathway forward.

This Report now goes on to develop a Roadmap that seeks to capture the value that CST can bring to the national energy system, in the most cost-efficient and effective way.

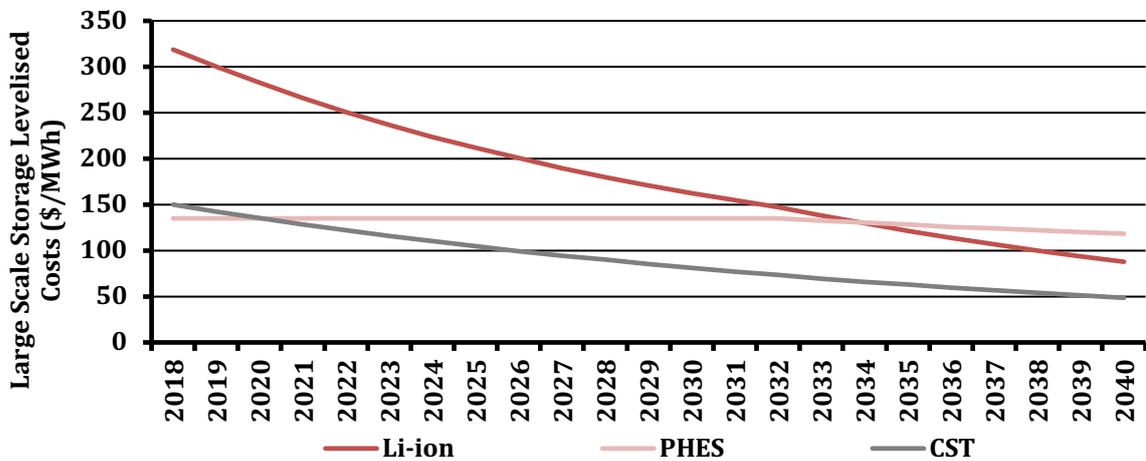
5.2 Headlines

1. The Base Case indicates a build of 3.94 GW resulting in \$2.0 billion (2018\$) of cumulative value for customers through lower costs by 2040. This represents a \$0.8 billion or 3% reduction in customer bills in 2040.
2. The No Regrets Case indicates a total build of 5.1 GW of installed capacity with 1.14 GW embedded within fringe-of-grid locations on the distribution network and a further 0.6 GW from off-grid systems resulting in \$3.4 billion (2018\$) in cumulative customer savings through to 2040. This does not include the additional economic activity identified by AITI, detailed in Attachment 3.
3. The High Case indicates 12.1 GW of installed capacity resulting in \$4.5 billion (2018\$) in cumulative customer savings through to the end of 2040. This also does not include the additional economic benefits identified by the AITI. 12.1 GW represents 30% of the 40 GW of new generation capacity that is forecast for development by 2040.
4. CST is an important enabler for the increased uptake of VRE technologies (i.e. PV and wind) throughout the next decade in fringe-of-grid locations as it provides one of the most cost-effective energy storage or dispatchability options at higher VRE penetration levels. This is indicated in figure 5 below, which compares the levelised cost of various installed large-scale storage technologies. This figure shows that CST's storage capability:
 - is lower cost than batteries for >1 hour of storage
 - becomes lower cost than PHES by around 2020

Australian Concentrating Solar Thermal Roadmap

- is lower cost than CCGT by 2031 and has no emissions¹⁷
- like PHES, has inherent ancillary services.

Figure 5 – Large-scale storage levelised cost per MWh exported



Source: Energeia analysis

Note: PHES and li-ion batteries have input costs of electricity purchased to ‘charge’ the storage. The model assumes charging occurs during off-peak times at low off-peak wholesale pricing, as calculated by the model.

5.3 Scenario results reveal logical pathway

Analysis of the modelling results in this section focuses primarily on the opportunities between the Base Case and No Regrets Case. This is because the analysis suggests that small targeted investment to convert the Base Case into the No Regrets Case will deliver a significantly larger benefit to energy consumers. This benefit includes improved security and reliability benefits for fringe-of-grid customers and communities as well as reduced customer bills across the NEM. Further, in bringing on earlier deployment in fringe-of-grid and off-grid locations, it effectively lowers the technical and financial risks associated with larger CST systems when required in the transmission network post 2030.

The Base Case results indicate a clear path for the development of CST projects and thus a CST industry in Australia. This Case shows that CST should commence a steady entrance into the national market for larger-scale projects connected to the transmission network from around 2030. This entrance is largely in response to the withdrawal of coal power stations due to age.

In the Base Case, CST’s entry will produce a reduction in wholesale market prices over the course of the decade of \$2.0 billion (NPV) or 6% out to the end of 2040 and culminating in a \$0.8 billion or a 3% reduction in customer bills in 2040.

¹⁷ There has been no definitive formula agreed as yet on the ratio of VRE to dispatchable energy in markets. There is however general agreement that the higher the penetration of VRE in the system, the more dispatchable capacity will be needed. CSIRO’s Low Emissions Technology Roadmap provides a credible discussion of this matter. www.csiro.au/en/Do-business/Futures/Reports/Low-Emissions-Technology-Roadmap pp. 115-117.

Australian Concentrating Solar Thermal Roadmap

The modelling results for the No Regrets Case indicate a way forward over the coming decade in the form of additional opportunities for earlier deployment in smaller-scale systems.

Smaller systems embedded within the distribution network would provide additional system strength benefits to the network in fringe locations across the NEM states at no or reduced cost to consumers, with improved reliability. There is a significant cost imposed on consumer bills each year due to the delivery of electricity through the distribution networks. Network costs in the fringe of grid can account for between 40% to 60% of a customer's electricity bill, depending on the jurisdiction.¹⁸

Each year distribution networks are upgraded and further extended at the fringe, with the cost passed on to network customers through their quarterly electricity bills. Consumers also pay more across the NEM due to the large losses that occur in getting electricity from the point of generation to a small number of customers in these outer regions. The modelling results indicate that there is around 1.14 GW of potential within the fringes of the distribution systems across the NEM's mainland states to develop CST projects. These projects would deliver electricity with significantly reduced losses and reduce the need for extensions and upgrades in these regions.

As indicated throughout this Report, CST provides many of the benefits that a secure and reliable system needs in one technology, especially in fringe-of-grid locations. These benefits include storage that enables a price competitive dispatchable capability and ancillary benefits including inertia, FCAS and FFR services, system strength/ fault current. These benefits are delivered by electricity without emissions.

In its 2018 *Economic Regulatory Framework Review: Promoting Efficient Investment in the Grid of the Future*, AEMC raised the issue of "changes required to the electricity distribution system to optimise the value provided by DER and whether the current regulatory framework can support NSPs [Network Service Providers] in efficiently integrating DER".¹⁹ AEMC acknowledged the grid is in a transformative process and that the relationship between the increasing development of DER and the impact this has on the operational and technical aspects of the networks is in an evolutionary phase.

The modelling shows that the development of CST systems operating in specific locations across these regions would save customers an important component of their electricity bills and improve system security and reliability. If some of these savings were transferred to CST generators to incentivise plant development at a smaller scale within optimal locations across the network, the development of up to 1.14 GW of new CST plant would be incentivised. This would also deliver a more secure and reliable system from a technology that provides reliable power and ancillary services without emissions making it an important recommendation in this Report for the AEMC to consider.

Energeia has also identified the emergence of a further 0.6 GW of development opportunity in the remote and off-grid markets, which will become cost competitive

¹⁸ http://www.energynetworks.com.au/sites/default/files/electricity-prices-and-network-costs_2.pdf

¹⁹ www.aemc.gov.au/sites/default/files/2018-07/Final_Report.pdf, p.v.

Australian Concentrating Solar Thermal Roadmap

from the middle of the next decade. This will include both mining operations and off-grid communities. The early demonstration of CST's operation and commercial structure from smaller fringe-of-grid systems, supported through the No Regrets recommendations, will lower the perceived and real risk to the risk-averse mining sector and off-grid communities. This is an important feature of the development pathway.

Furthermore, the deployment of smaller CST systems in the distribution network will have a beneficial impact on the future deployment of large-scale systems in the transmission network from 2030. These smaller systems will demonstrate a good technical and commercial understanding of CST technology, grow Australia's capability and capacity to build and deploy CST systems and importantly, lower the technology cost and financing risk associated with CST systems.

If the High Case emerges, deployment will be accelerated because the cost of CST will be lower as a result of higher global deployment rates. The implementation of the proposed recommendations will simply have prepared the sector for earlier commercial deployment. Higher international deployment rates, in line with the High Case scenario adopted in this Report are anticipated in the NREL initiative, the Concentrating Power Gen3 Demonstration Roadmap. The NREL Roadmap considers that the three most likely pathways for CST - molten salt, falling particle and gas phase – have the potential to achieve the goal of USD0.06/kWh within the next ten years.²⁰

5.4 Competitiveness with other dispatchable technologies

The electricity market is not facing an undersupply problem over the coming decade, it is facing a challenge from the alignment of the supply of electricity from VRE with demand.

CST, like hydro generation, has several significant differentiators from other renewable energy systems including PHES systems.

- CST systems collect solar energy, which is stored in a tank for later use. The energy can then be used to generate electricity when it is needed rather than when the solar energy is available. This is much the same as gas or coal except for two important differences:
 - Fossil fuel systems use energy that was created thousands of years ago and stored by nature. It is extracted from a coal or gas 'storage system' and used to create heat when it is needed for electricity production.
 - Burning fossil fuels emits greenhouse gases and other pollutants, whereas CST has zero emissions.
- Like hydro, CST collects and stores solar energy, as described above, without the need for immediate conversion to electricity. This energy can be later converted to electricity when it is required. This compares to PHES, PV with batteries and wind with batteries, which all require the original input of energy to be converted to electricity and then converted into chemical energy as it is stored

²⁰ <https://www.nrel.gov/docs/fy17osti/67464.pdf> p.116.

Australian Concentrating Solar Thermal Roadmap

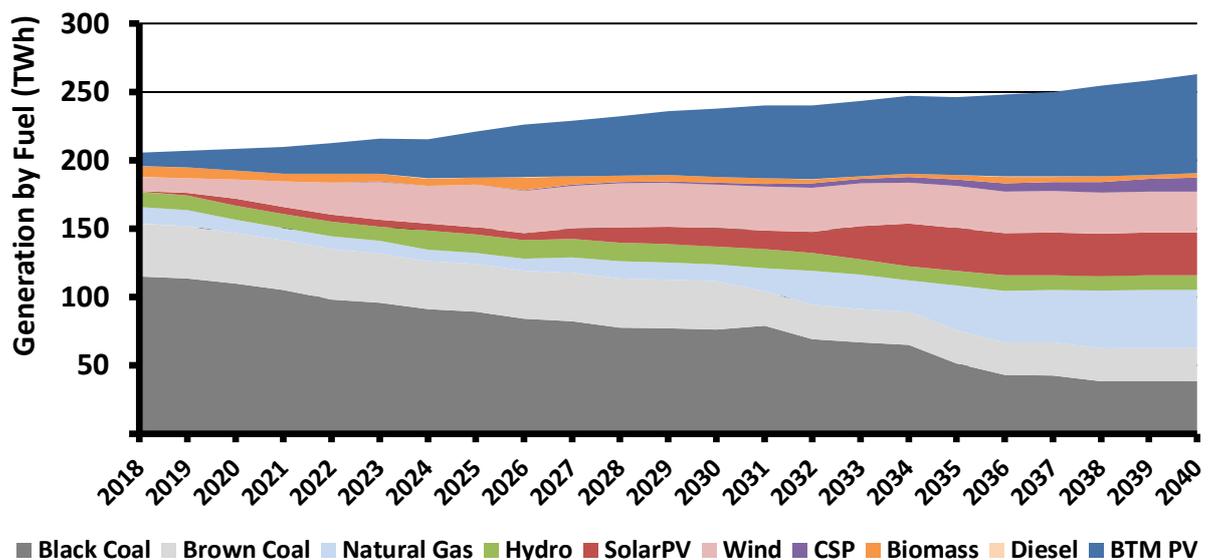
in the battery or as potential energy in a PHES up-stream dam and then converted back into electricity for dispatch.

Each conversion results in losses as the conversion efficiency is less than 100%. This results in lower overall efficiency as more energy is needed as an input for a given amount of energy to be exported. These processes add to the total amount of energy needed in the market and to costs.

- A CST system turbine is a rotating device that effectively mimics traditional fossil fuel generators and provides the same ancillary services that the grid currently relies on fossil fuel generators to provide. As fossil fuel generators retire, CST can provide the energy, the dispatchability and the ancillary services that the network depends on.

The modelling clearly shows that CST can make a significant contribution over the next decade to the resolution of the VRE and dispatchability or reliability problem, and that it can support an increasing penetration of VRE deployment as shown in Figure 6. The CST contribution is relatively small but nonetheless significant as the lowest-cost enabler.

Figure 6 – Dispatched energy by generator type – No Regrets Case



Source: Energeia modelling

Note: BTM PV is behind-the-meter commercial and domestic PV.

CST is less exposed to a reliance on arbitrage than wind or PV with storage and less dependent on geology than PHES. It is also sufficiently scalable to fit comfortably into smaller parts of the distribution network or play a high-profile role in larger-scale deployment connected to the transmission system. CST is not dependent on biomass production or the energy expended in the collection process. Operationally, CST competes directly with new CCGT though CST will become lower cost over the next decade or so and has no emissions.

Note: ITP produced a report for ARENA considering a range of dispatchable renewable energy technologies, including CST. This report was developed from a different

Australian Concentrating Solar Thermal Roadmap

perspective than the CST Roadmap. The Dispatchability Study compares the various dispatchable technologies on an LCoE basis, that is, what will be the LCoE of each technology over time. In contrast, the CST Roadmap asks the question ‘how and when would the market take up CST because it is economically beneficial (to the market) to do so?’

The Roadmap modelling, performed by Energeia, enables all technologies available to the network to enter when they provide the lowest-cost solution to market needs at any given point and at any given time., In essence, the economics objectively determine if and when market behaviour will result in individual generators of all technology types entering the market. The economics do not consider what the technology is, just how it can respond to the needs of the market as well as its value in meeting those needs, and then it configures the most economic dispatch.

Having established the economic benefits of where and when CST enters the market, the Roadmap goes on to consider how best to ensure that CST is ready to deploy and provide its benefits into the market.

5.5 Comment on value of ancillary services

Despite the increase in the need for FCAS services in line with the increasing penetration of VRE into the system through to 2040, Energeia found that “there is not sufficient revenue to deliver a meaningful value stream to CST” that is, the value is not sufficient to drive investment decisions.²¹

5.6 Emissions reductions

Further, the modelling considers the merit order and cost competitiveness of replacement technologies for coal and gas if emissions constraints are increased from 2030. For example, in an extreme case, Energeia’s modelling shows that the lowest-cost NEM solution under a zero emissions target from electricity supply in 2040 would require 21.4 GW of CST. This would comprise nearly half the 40 GW of electricity generating capacity that needs to be built across the NEM over the course of the next two decades to meet demand due to the retirement of coal. This result clearly demonstrates a further rationale for developing CST as a cost-competitive solution in preparation for further emissions reductions and as risk mitigation for any further government climate change commitments and interventions that might occur into the future.

However, at the time of writing, there were no signals within the Australian energy market that coal and gas generation will be retired completely from the market by 2040. Further, the emergence of technologies not considered in this Report such as hydrogen, or the advent of more aggressive emissions reduction initiatives, while possible, are far too uncertain to include.

The role of technologies such as the use of hydrogen as a ‘fuel’, geothermal and ocean energy in the national energy landscape are still too uncertain to model reliably. As referred to often throughout this Report, it is reasonable however to assume that coal

²¹Energeia Report P.26

Australian Concentrating Solar Thermal Roadmap

plant will increasingly withdraw from the national energy landscape due predominantly to age and the reasonable expectation of further emissions reduction targets post 2030.

The modelling undertaken for this Report assumes a 50-year life span for the coal-fired power stations currently operating across Australia's electricity systems. As the following table shows, by 2040 more than half of these power stations will have reached a 50-year life span.

Australia's operating coal-fired power stations							
State	Power station	Primary fuel type	Year of commissioning	Announced year for exit	Age (2018)	Age (2040)	Capacity (MW)
NSW	Eraring	Black Coal	1982-84		34-36	56-58	2880
NSW	Bayswater	Black Coal	1982-84	2035	34-36	56-58	2640
NSW	Liddell	Black Coal	1971-73	2022	45-47	67-69	2000
NSW	Mt Piper	Black Coal	1993		25	47	1400
NSW	Vales Point B	Black Coal	1978		40	62	1320
VIC	Loy Yang A	Brown Coal	1984-87	2048	31-34	53-56	2210
VIC	Yallourn W	Brown Coal	1975,1982		36-43	58-65	1480
VIC	Loy Yang B	Brown Coal	1993-96		22-25	44-47	1026
QLD	Gladstone	Black Coal	1976-82		36-42	58-64	1680
QLD	Tarong	Black Coal	1984-86		32-34	54-56	1400
QLD	Stanwell	Black Coal	1993-96		22-25	44-47	1460
QLD	Callide C	Black Coal	2001		17	39	810
QLD	Milmerran	Black Coal	2002		16	38	851
QLD	Kogan Creek	Black Coal	2007		11	33	750
QLD	Callide B	Black Coal	1989		29	51	700
QLD	Tarong North	Black Coal	2002		16	38	443
QLD	Yabulu (Coal)	Black Coal	1974		44	66	37.5
QLD	Gladstone QAL	Black Coal	1973		45	67	25
WA	Muja	Black Coal	1981, 1986		32-37	54-59	1,070
WA	Collie	Black Coal	1999		19	41	340
WA	Bluewaters 1	Black Coal	2009		9	31	208
WA	Bluewaters 2	Black Coal	2010		8	30	208
WA	Worsley (Alumina)	Black Coal	1982-2000		18-36	40-58	135

Senate Environment and Communications Reference Committee, *Final Report: Inquiry into retirement of coal fired power stations*, 29 March 2017. Australian Energy Council Submission 44, p.5. (updated)

The assumption of a 50-year life cycle is deliberately conservative to avoid controversy over early retirements. The average life span of the 10 coal-fired power stations that have retired from the nation's electricity systems across NSW, Queensland, South Australia and Victoria over the course of the past decade is 40 years.

At the time of writing, the ESB was in the process of finalising its advice on the NEG incorporating a reliability requirement for regions across the NEM as well as a national emissions reduction target. It can reasonably be expected that storage or dispatchable

Australian Concentrating Solar Thermal Roadmap

technologies will be incentivised through the NEG. Should the post 2030 Paris Agreement process see Australia commit to further emissions reductions, these would be reflected in the NEG and impact on post 2030 outcomes that cannot be addressed within this Report.

Australia is currently considering its programs to be presented to the UNCCC in 2020 that can reasonably be expected to reduce emissions. Considering the resulting impact from both processes together, it can reasonably be expected that further incentives for the development of technologies with emissions reduction and system security and reliability capabilities such as CST will be required post 2030. These would further advantage CST given its strong performance in low-cost, lower emissions modelling outcomes.

5.7 Low-hanging fruit for early deployment

The immediate opportunity is to demonstrate that CST's technological, commercial and other characteristics such as system strength can be achieved through the development of smaller projects located in the distribution network or off-grid.

The development of a small number of smaller projects will enable the market to understand CST as an energy technology and then facilitate further investment in other similar installations across the NEM (and potentially the SWIS), as well as in fringe-of-grid and off-grid locations once they become commercially competitive in 2022 and 2025 respectively.²²

Once these projects are deployed, CST will be better understood in the Australian market context and ready to deploy into the market earlier than the Base Case's 2031 timeframe. As discussed in more detail below, this will be important for market security and reliability as the retirement of coal-fired plant occurs throughout the coming two decades.

CST's earlier development can ensure the energy system gets these benefits as part of an integrated lowest-cost approach. This would enable it to be ready to deploy at large scale to make its vital contribution from the time coal generators commence an ongoing exit from around 2030.

The clear rationale for providing support is as follows:

- The cost curve projections will be realised through the impact of technology improvement interventions linked to manufacturing improvements, economies of scale and targeted research both in Australia and internationally.
- The modelling shows that within 5 years, the economic savings in the market from the development of fringe-of-grid systems to offset grid enhancement costs and to reduce losses at and around the fringe of the distribution network is \$0.41 billion in net present value (NPV) terms.
- There is a demonstrated benefit for the development of smaller CST systems that also produce an income stream from the utilisation of waste heat. While the

²² A reminder that when this Report discusses smaller systems it refers to small, highly bespoke systems in the 1-5 MW range and mid-sized systems up to 30 MW, which is the limit of DER projects that can be deployed in the distribution network.

Australian Concentrating Solar Thermal Roadmap

modelling for this Report has not focused on the additional value that this would produce, the development of these systems will enable an examination of the cost structures and value streams from these projects. This can also be through an early demonstration project alongside the opportunity to consider broader industry development opportunities where heat is a required input.

- To ensure transmission-connected utility-scale CST is available to provide the system security and reliability benefits that it offers by the time it is needed in the NEM, so that sub-optimal or piecemeal and ultimately higher-cost responses to the withdrawal of coal from the market over the course of the next two decades are avoided.

5.8 The rationale for incentivising early deployment

Several stakeholders have raised concerns that there needs to be a signal for the market to respond to impending coal closures to achieve the orderly transition at lowest cost to the system and maintain system security and reliability.

The Finkel Review recommended that coal generators be required to give three years' notice before closures to avoid supply shortages and system instability.

To support the orderly transition, the Panel recommends a requirement for all large generators to provide at least three years' notice prior to closure. The Australian Energy Market Operator should also maintain and publish a register of long-term expected closure dates for large generators.²³

The three years' notice provision will provide CST developers and the wider electricity sector with a clear signal to scale up for broader deployment in line with the modelling results. Further, and importantly, if early deployment is incentivised and occurs, the CST sector will be able to do so with a decade or more of experience in demonstrating the technology and the commercial value of projects. CST will not have to go through a period of uncertainty to gain confidence from lenders and EPCs at the time it will be most needed in the national market and will be ready to deploy without subsidies on a value basis.

Recommendations are identified in Section 10 of this Report that could be implemented by governments, regulatory bodies, the research sector and the CST industry itself to bring the deployment of CST forward. These recommendations will ensure that it will be ready to add value over the course of the coming decade and make its larger contribution when needed.

These recommendations are strongly informed by the views and inputs from a wide range of stakeholders consulted as part of this Report.

6 Industry development

JHA commissioned the AITI to consider opportunities for industry development that could be driven by successful CST deployment in Australia. This study (see Appendix 3)

²³ Finkel Review Panel, *Independent Review into the Future Security of the Australian Electricity Market: Blueprint for the Future*, 2017, Recommendation 3.2, p. 23.

Australian Concentrating Solar Thermal Roadmap

focuses on the potential for Australian businesses to engage in the CST value chain through the provision of key components and services.

6.1 The CST value chain and Australian businesses

The CST value chain comprises manufactured components such as:

- solar collection systems including mirrors, heliostats, receivers, fabrication and support structures
- control and integration systems
- thermal conversion systems including pumps, boilers, storage, piping and valves
- electrical conversion systems including power blocks, balance of plant and turbines.

The value chain also involves R&D activities to reduce the costs involved and increase the safety, effectiveness and durability of components.

Investment and financing form an important part of the value chain as do various service providers including:

- developers and engineering, procurement and construction (EPC) contractors
- civil works businesses
- operation and maintenance (O&M) suppliers.

While the CST industry is at an embryonic stage in Australia, a number of local organisations across the country have capabilities to engage in the CST value chain, particularly around solar tower construction, integration systems, support structures, heliostats and services including EPC and civil works.

6.2 Spillovers

The AITI identified that spillovers would occur from CST development to many other sectors including automotive, glass, metal, power and process heat, wires and cables, water, chemistry, electronic, cement and other renewables such as PV and wind.

Regional development opportunities also arise from CST deployment, particularly in areas with the presence of existing power network infrastructure, transport through rail and shipping facilities and transferable manufacturing capabilities. CST plants can result in a number of benefits such as employment, particularly as project development involves the use of a higher proportion of local services compared to PV and wind, for instance via construction and assembly activities.

AITI's full analysis can be found at Appendix 3.

Australian Concentrating Solar Thermal Roadmap

7 Indirect economic benefits

JHA commissioned AITI to consider the economic impact of the CST sector under various scenarios. As in the industry development analysis, the focus in this section is on the Base Case and the No-Regrets Case. Both higher and lower outcomes are possible but the consideration of the Base and No-Regrets cases best represent the most likely outcomes and provide the more assured value when considering economic impact resulting from policy initiative decisions.

In considering the economic activity that would result from an active CST sector, AITI looked at what local content could be achieved, how it could be met, and in which sectors as well as where and when. The local content ratios used were conservative, not to impose quotas to achieve a market-distorting outcome but rather to reflect a natural level and its natural growth as the sector matures.

AITI's detailed report at Appendix 3 provides analysis of economic benefits and industry opportunities by sector and by state. In summary:

- Australia already has the skills and resources to provide much of the services that will be required by the CST sector.
- Australian research has resulted in the development of intellectual property either aimed at or applicable to the CST sector.
- Australia has the capability to provide a number of manufactured components for CST and the capacity to expand this as the sector matures and grows, but will always be an importer of some significant components including power blocks.
- The No Regrets Case sees significant additional investment. The value of this additional economic activity is amplified by the fact that it is earlier, so has a higher NPV impact, and is focused on regional locations.

AITI looked at both direct and indirect economic and employment benefits. In addition to the economic impact of CST deployment and operating activities, Energeia's modelling considered the impact of CST on customer electricity bills, which will add additional economic value to the community over and above those established by AITI's work.

The quantum of CST economic and employment activity varies from year to year. This is because construction phases, which last for 2-3 years, generate more activity than operations and maintenance phases.

7.1 The economic model

An economic impact model was developed for CST deployment by state under two scenarios, which are summarised in Table 1 below:

1. Base Case: This assumes that CST will enter the market from 2031 if initiatives and policies in place today are maintained. Over the 10 year period from 2031 to 2040, development activities involve CAPEX of \$5.0 billion and local expenditure of \$2.3 billion. This results in a contribution to gross state product (GSP)²⁴ of \$0.8

²⁴ GSP in Queensland, South Australia and Victoria

Australian Concentrating Solar Thermal Roadmap

million (direct) and \$1.6 billion (indirect), along with approximately 4,500 full-time-equivalent (FTE) direct and 8,800 FTE induced years of employment.

2. No Regrets Case: In this case, CST investments are brought forward from as early as 2022 and there are higher expenditures in NSW, QLD, SA and VIC. Over the period 2022 to 2040, this scenario involves a CAPEX of \$9.2 billion and local expenditure of \$4.7 billion. It results in a GSP contribution of \$1.7 billion (direct) and \$3.5 billion (indirect) and the employment of 9,500 and 19,000 years of FTE employment (indirect).

Table 1: Economic and employment impact of CST deployment under the No Regrets Case between 2022 and 2040

Scenario	CAPEX (\$B)	Local content (\$B)	Economic impact		NSW	QLD	SA	VIC	Total
Base Case	5.0	2.3	Contribution to GSP (M)	Direct	\$0	\$179	\$418	\$226	\$823
				Induced	\$0	\$371	\$763	\$491	\$1,625
				Total	\$0	\$550	\$1,181	\$717	\$2,448
			Employment (FTEs)	Direct	0	992	2,314	1,251	4,557
				Induced	0	2,012	4,097	2,642	8,751
				Total	0	3,004	6,411	3,893	13,308
No Regrets Case	9.2	4.7	Contribution to GSP (M)	Direct	\$243	\$653	\$510	\$315	\$1,721
				Induced	\$544	\$1,352	\$931	\$685	\$3,512
				Total	\$787	\$2,005	\$1,441	\$1,000	\$5,233
			Employment (FTEs)	Direct	1,344	1,352	931	685	4,312
				Induced	2,914	3,616	2,826	11,746	21,102
				Total	4,258	4,968	3,757	12,431	25,414

Source: AITI

While these estimates are conservative, it is clear CST provides a considerable opportunity with a significant forecasted impact on the economy and employment.

7.2 Base Case

Taking a business as usual approach, assuming no material changes to policy, regulation and targets other than those either in place or accepted as going to happen, the analysis (see previous Table 1) indicates the following outcomes, driven by CST deployment, through to the end of 2040:

- estimated additional economic activity of \$2.4 billion (2018 \$) excluding any potential benefits that may arise from customer bill reductions
- additional 13,000 FTE years of employment.

7.3 No Regrets Case

The No Regrets Case is the Base Case plus an initiative to transfer savings delivered via reduced network costs to generators that create those savings. It results in significant additional impacts across all three areas of economic activity, employment and bill savings. The analysis for the No Regrets Case (see previous Table 1) indicates the following outcomes, driven by CST deployment, through to the end of 2040:

Australian Concentrating Solar Thermal Roadmap

- estimated additional economic activity of \$5.2 billion (2018 \$) excluding any potential benefits that may arise from customer bill reductions
- additional 27,000 FTE years of employment.

7.4 Base Case versus No Regrets Case

The following sets out the difference in economic and employment benefits between the Base and No Regrets cases on a state-by-state basis.

Table 2: CST driven economic benefit (2018 \$) by state for the period 2018-2040

	Base Case \$M	No Regrets Case \$M
NSW	\$0	\$786
QLD	\$550	\$2,005
SA	\$1,181	\$1,441
TAS	\$0	\$0
VIC	\$717	\$1,001
Total	\$2,448	\$5,233

Source: AITI

Figure 7: CST driven employment expressed as FTE years by state for the period 2018-2040

	Base Case (FTEs)	No Regrets Case (FTEs)
NSW	0	4,259
QLD	3,004	10,949
SA	6,411	7,827
TAS	0	0
VIC	3,894	5,432
Total	13,309	28,467

Source: AITI

Australian Concentrating Solar Thermal Roadmap

8 Stakeholder consultation

JHA undertook a broad and extensive consultation process with numerous face to face interviews and some phone teleconferences across the full range of participants in the relevant areas of the energy industry. These participants included industry bodies, the finance and regulatory sectors, the CST and broader energy sector including the largest through to the smaller companies and the federal and relevant state governments. This process provided the opportunity to discuss views on opportunities and barriers to the uptake of CST in Australia at considerable depth.

Nearly all interviewees viewed the potential for CST technology in Australia favourably with the obvious single biggest concern being the potential to reduce its LCoE.

Overall the most often cited favourable views are summarised in the following categories:

- CST is a key enabler for higher penetrations of VRE
- CST's dispatchable capability provides important benefits to the NEM - stakeholders were hopeful the NEG would provide the necessary support to close the LCoE gap
- as a thermal technology it is an obvious replacement for the retirement of coal-fired infrastructure within the NEM
- CST needs to be up and running in Australia in readiness for the retirement of coal-fired plant.

Overall the most often cited unfavourable views could be summarised around the following categories:

- LCoE is too high and not coming down soon
- CST is a complex technology that is not understood in Australia
- bad track record of deployment in Australia
- commercial case for storage and therefore dispatchability is not clear
- global uptake is not accelerating.

8.1 CST developers

CST developers consistently stated their major barriers to development are:

- inability to get funding, including income stream from the RET, government grants and private sector finance
- RET does not recognise storage, only LCoE
- inability to get bankable power purchase agreements from the retail market leaders
- no adequate technology/engineering expertise in Australia
- lack of value on time of day generation for developers and CST project owners undermines commercial case.

8.2 Finance sector

The finance sector also raised consistent barriers for CST developers to gain access to lenders and equity investors prepared to be part of financing for CST projects, which are:

Australian Concentrating Solar Thermal Roadmap

- lack of understanding how the CST technology works, sector cannot see it operating in Australia to make an assessment
- lack of understanding around the commercial case for CST against the case for PHES and batteries as arbitrage market diminishes
- some knowledge of unsuccessful Australian projects among technology and infrastructure funders
- lack of clarity around the technical and commercial success of international projects
- no clear demonstration of the revenue stream from CST projects under current market conditions.

Despite the focus on barriers, the finance sector stakeholders generally expressed good will towards CST as a generation technology with a dispatchable capability. There is a clear understanding that the market will need dispatchable renewable technologies and that CST is the obvious front runner on the horizon. However, until the sector can see successfully operating plant that demonstrates how the technology works alongside market rules, or policies that value its dispatchable capability and other ancillary benefits, they do not see a clear pathway to investment.

8.3 Electricity sector

The leading generator/retailer businesses have generally offered similar views to the finance sector, both in terms of the barriers to development and the potential for CST to be a major energy supplier in the future. Most companies in this category have devoted significant resources to analysing the potential market for CST and initially expressed hope that the NEG might bolster the case for either development internally or PPA purchase from a CST developer.

Despite the barriers, stakeholders in the energy sector, like stakeholders in the finance sector, generally expressed good will towards CST as a generation technology because of its dispatchable capability. As with the finance sector, there is a clear understanding across the electricity sector that the market will need firming renewable technologies and that CST is the likely option. However, also in line with the finance sector's view, the electricity sector wants to see successfully operating plant in Australia, which demonstrates that the technology works alongside effective or adequate market rules or policies that value its dispatchable capability before committing to the technology.

8.4 State governments

JHA has engaged with the state governments across the mainland NEM states that have generally been very supportive of CST, with both South Australia and Queensland taking significant steps in 2017 to support the deployment of CST projects within their jurisdictions.

A further area of interest within the states, particularly in Victoria and Queensland is the opportunity to combine heat and power from CST projects to support and attract local industry. The states are very interested in further analysis and coordination of the industry development and jobs aspects of this potential development.

Australian Concentrating Solar Thermal Roadmap

9 Three key focus areas

The following three key focus areas are proposed in response to the findings in the modelling undertaken by Energeia and the views of stakeholders. The imperative is to identify areas where there is the 'lowest hanging fruit' or the maximum value for CST developers and generators from the entry of their projects into the system – with the greatest economic benefit to consumers.

Three focus areas have been identified to demonstrate both the technical and commercial viability sought by the finance sector and the broader energy sector so that they can assess both the technology and the commercial viability of projects.

The following three focus areas provide a clear and logical pathway that has been laid out by both the modelling results and the input from the full range of stakeholders across the CST and broader energy sector. Together, these three areas provide the foundation for the development of the CST sector in Australia. The three focus areas are:

1. Smaller systems (1-30 MW systems)
 - a. developing projects utilising existing technologies embedded within the distribution network including at the fringe of grid
 - b. developing off-grid projects
 - c. developing projects demonstrating emerging technologies with a particular focus on Australian IP
 - d. developing CSP systems that operate behind-the-meter supplying both electricity and heat for industrial processes such as food processing.
2. Research alignment with industry needs.
3. Widespread uptake of CST Systems - A contribution to the 4 Finkel outcomes.

Australian Concentrating Solar Thermal Roadmap

10 Recommendations

This Report has interrogated the case for the deployment of CST in Australia. The modelling has established a clear pathway for supporting staged deployment in line with both the forward cost projections and the additional values that CST provides. The following recommendations form an integrated strategy that incentivises the values that CST offers to the NEM. Together, they form a Roadmap for the development of a CST industry in Australia.

These recommendations are presented in line with the proposed focus areas. The objective of this Roadmap is to identify and propose specific initiatives that enable the contribution of CST's specific market benefits to ensure that they are provided to the market where and when they deliver the best value to the market. Several of the recommendations broadly support the development of other dispatchable energy technologies.

The rationale for undertaking this Report and developing the Roadmap is to determine whether the broader range of benefits that CST has to offer justify support to assist it into the market and if so, to identify initiatives to deliver that support. As the modelling shows, CST's entry into the market delivers significant value to the electricity system and customers. CST is a vital part of the response to the withdrawal of coal generation from the market over the coming years if the four objectives identified in the Finkel Report are to be met.

The Roadmap demonstrates how CST's entry into the market will enable the orderly transition of the electricity system at lowest cost.

10.1 FOCUS AREA 1: Smaller systems connected in the distribution network and off-grid

The recommendations in this, the first focus area are designed to support the development of 1.14 GW in CST systems across the NEM's distribution systems and a further 0.6 GW in CST systems for off-grid communities, including mines. These smaller systems provide low emissions electricity, network services (including system security) and reliability and cost benefits to customers. These recommendations in essence, drive the difference between the Base Case and the No Regrets Case.

10.1.1 ARENA Initiatives

10.1.1.1 Grant funding for a small number of smaller distribution-connected projects

<<< Key Roadmap Recommendation >>>

Throughout the stakeholder engagement process for this Roadmap it has been clear that institutional lenders are unfamiliar with the technical and commercial aspects of CST projects in the Australian context. Accordingly, future lenders and equity investors would likely require a risk premium for early projects. It has also been clear that this premium will continue to be a significant barrier to project development until technology success and the commercial case can be demonstrated across a small number of projects.

Australian Concentrating Solar Thermal Roadmap

Further, stakeholders across the network management sector raised the potential for smaller projects to enhance the grid in fringe-of-grid or off-grid areas.

The confluence of these two matters lends itself to a very visible demonstration of a small number of small to mid-size projects leveraging ARENA support in the form of smaller grants. These grants will assist in demonstrating to lenders and investors, the broader energy sector including EPC companies, and market regulators and operators that CST is technically and commercially viable. This will initially be in bespoke configurations and fringe-of-grid locations. In this way, confidence can be built in the CST sector, enabling it to build scale and be ready to compete with other generation and storage technologies. Most importantly, it will enable CST to be available within the Australian market to replace the attributes of coal generation as coal infrastructure retires from the market in the coming decade and beyond.

Further, a number of CST developers also indicated the importance of the potential revenue stream from the sale of 'low-grade heat', which at relatively low temperatures is essentially a waste product from the electricity production process. While heat production was not initially part of the focus for this Roadmap, the analysis shows that it is an important part of the development of a commercial pathway for CST, and that it has the potential to replace heat produced from the burning of fossil fuels. This, in turn, would contribute to the reduction of emissions across the energy sector.

CST, particularly smaller CHP systems, can create opportunities for broader economic development in regional centres by:

- improving the quality of electricity supply in a regional area to attract industries that are dependent on stable supply and might otherwise see the local supply as a barrier
- providing opportunities for green-field industry development, as initially demonstrated by Sundrop Farms at Port Augusta, South Australia
- providing a proportion of the energy collected from the sun for processing applications such as food processing (e.g. dairies, abattoirs and adding value to fruit and vegetable production), either reducing energy costs for existing operations or creating new green-field opportunities
- providing low-grade 'waste' heat for applications such as hydroponics and aquaculture
- creating opportunities for products to be produced and marketed as being from a 'zero emissions manufacturing facility'.

The mainland NEM state governments have been consulted throughout the development of this Report and all have expressed interest to varying degrees in the benefits provided by new dispatchable generation in regions including the potential for the provision of heat for processing industries.

ARENA can call for an Expression of Interest (EoI) from CST developers, potentially in partnership with state governments and network companies, to develop smaller CST systems in a range of configurations including:

- fringe-of-grid locations where avoided network upgrade costs and electricity losses are offset by CST deployment with storage

Australian Concentrating Solar Thermal Roadmap

- fringe-of-grid locations where the potential and economic case exists to sever connection with the network
- locations where the potential exists to provide electricity to a specific industrial user, behind the meter, with or without the potential to sever connection with the grid
- off-grid including remote locations
- CST deployment located within the distribution network where industrial users require both electricity generation and heat for a specific commercial or industrial purpose
- Fringe-of-grid or in an appropriately zoned location near to multiple customers where CST developers can demonstrate a pathway to a commercial case for electricity generation in conjunction with the commercial use of heat.

Upon receipt of EOIs, ARENA can invite full applications to the most prospective of responses from both a commercial and technical viewpoint across the proposed configurations for grant funding. A consideration of the leverage offered by state governments, network operators or any other proposed partners should also play an important part in the assessment process.

Grants can enable early projects when emerging technologies are more expensive. EPCs apply significant wrap penalties, suppliers are not geared up for supply at scale and high risk premiums are placed by lenders.

The 1.7 GW of potential identified in the modelling for these smaller systems is split between current fringe-of-grid locations (1.14 GW) and off-grid industrial users (0.60 GW) across the mainland NEM states. The case studies that these early projects would provide, through ARENA's knowledge sharing requirements, would provide an invaluable asset to future developers and lenders. ARENA may find that the potential for other configurations or more than one project in a proposed configuration represents significant value for money and thus justify additional support for projects adopting similar configurations.

Within 2 years, ARENA could see several projects assessed and under development.

10.1.1.2 Heat and power mapping

ARENA can approach the NEM mainland states, Western Australia and the Northern Territory to jointly develop heat and power maps where the following conditions align with a focus on where the states and territories see opportunities for regional development:

- a single large heat and power user or industry cluster requiring heat and power
- close to appropriately zoned and large enough areas of land to build CST infrastructure
- with the preparedness of state governments to invest in attracting industry to the location.

Australian Concentrating Solar Thermal Roadmap

10.1.1.3 A finance 'product' for smaller behind-the-meter CST systems with CHP or potentially just heat

Smaller behind-the-meter systems (typically <2 MW_e) will usually include at least some use of heat for processes such as food processing or cleaning.

The business model for these systems should be agnostic about whether the energy produced is used for heat or electricity supply. The split between the two will be bespoke and determined during system design.

Typically, the off-taker or energy consumer sees energy, in the form of either electricity or gas, as an input to their process that is provided by others. Investing in energy production is not their key business. As a result, a preferred supply solution would be for a third party to own the generating assets and sell the energy to the off-taker. This is a financing opportunity similar to a behind-the-meter PV system, although it is likely to require a larger system and the energy output will be a mix of electricity and process heat.

There are early adopters looking at this opportunity in Australia, with Sundrop Farms having already demonstrated the concept. The market is restricted to entities that need heat as well as electricity, and also have a site suitable for the installation of a CST system within a suitable solar resource zone. Through the consultation process, JHA became aware that there are already companies and industry associations actively looking at vertical markets in Australia, but at the time of writing public announcements had not yet been made.

This market has not had the advantage of support through the RET because the heat component is not eligible for LGCs and the RET will cease in 2020.

ARENA's knowledge sharing requirements for the projects it supports will promote the demonstration of commercial and technical feasibility of the technology to facilitate further uptake.

From a financing point of view the barriers include:

- This is a relatively new approach to supplying energy within a business premise although there are a growing number of successful examples.
- There is little known about the approach within the potential off-taker market.
- Generating assets become stranded assets if the off-taker defaults.
- The transaction size is likely to be smaller than ideal.
- The integration with the off-taker's processes is going to be bespoke.

Embedded CHP systems offer strong protection from increasing gas and electricity prices for suitable medium to large businesses. Energy supply is a significant cost component in their operations and CHP systems offer the opportunity to more independently manage these costs. The most likely opportunities are located in regional areas where land is not priced at a premium and where there are significant opportunities for regional development and clean and green product manufacturing and branding.

To support the ongoing development of CHP systems from the initial base supported through the abovementioned grant program for smaller systems, ARENA can approach the CEFC to develop finance packages for these projects. These packages then need to be

Australian Concentrating Solar Thermal Roadmap

promoted to appropriate CHP developers, industry sectors and relevant state and local governments, where prospective regions are identified through state government development plans and through the heat mapping initiative.

10.1.2 Government initiatives

10.1.2.1 Transferring value to CST generators

<<< Key Roadmap Recommendation >>>

JHA considers this the most important initiative to emerge from the Roadmap process. It is an area currently under the microscope of governments and NEM operators and regulators, and is an area of significant complexity.

The modelling results have shown there is a total of around 1.74 GW of smaller system potential under the No Regrets Case. About 1.14 GW of this potential is embedded within the distribution network in fringe-of-grid locations and a further 0.60 GW is in more remote, off-grid locations. This potential can be realised if the value that these CST systems provide to the national energy system was available to the CST system generator. Customers would not only get a better service at no additional cost, they would also get an additional saving of \$1.4 billion out to 2040. This benefit would flow through to both NEM customers and off-grid customers. If this value is made available to CST generators, fringe-of-grid systems would start entering the market in 2022, and the off-grid systems from around 2025 on the basis of cost competitiveness.

The cost of investment in network upgrades is increasingly problematic. Distribution network service providers (DNSPs) are continually expanding the network into the outer regions of the grid to service smaller communities, which is increasing cost burdens across the entire system. Ageing network infrastructure is also becoming a barrier to new distributed generation. The deployment of CST systems in these regions is consistent with the general thrust of the energy transition, which will see technologies with storage or dispatchable capability distributed throughout the network.

This will avoid the need for an increased investment in new network infrastructure in some locations, as DER increasingly becomes a more optimal generation solution for both commercial and domestic or behind-the-meter users. Developers in outer regions of the network are frequently burdened with the costs associated with upgrading substations and the costs of poles and wires to enable connection. This in turn adds to the cost of new generation.

The 1.14 GW of smaller CST systems within the fringe of grid are viable without subsidy if they receive the value of the network savings. The model assumes they receive this value on a per MWh basis, ensuring the savings are actually delivered back to the system.

The value that CST systems, and any other DERs offering the same suite of benefits, in the 'low hanging fruit locations' comes from:

- no or reduced need for an increased investment in new network infrastructure in these locations
- no or reduced need for investment in network upgrades in these locations
- the avoided cost of losses from electricity travelling longer distances across the network to reach customers.

Australian Concentrating Solar Thermal Roadmap

The additional system strength benefit of electricity generated in the fringe could be the severing of access to the grid, producing a microgrid that will help to produce greater reliability across the NEM system. This would deliver a more robust, secure system and lower costs to consumers with the deployment of a technology that provides reliable power and ancillary services without emissions.²⁵

Further, the analysis undertaken by the AITI for this Report indicates that there is significant economic value in developing these systems for state economies. While not the fundamental interest of bodies that govern and regulate the NEM, it is in the interests of the state governments across the NEM to support projects that deliver broader economic benefits. These benefits are detailed in Appendix 3.

There are a number of reviews underway within the energy market regulatory and policy framework that are relevant to this recommendation, including:

The Energy Council

The COAG Energy Council has overarching responsibility and provides policy leadership for Australian gas and electricity markets²⁶. The Energy Council has a number of active projects underway, including Energy Market Transformation, that are directly related to this recommendation. The Energy Market Transformation Project Team (EMTPT) has responsibility for the projects linked to the energy market transition including *Stand-alone Power Systems* and *Network Regulation – Optimising network incentives*²⁷.

These projects involve policy development in conjunction with the regulatory bodies and state jurisdictions around the core issues relating to the regulation of ‘off-grid’ stand-alone power systems and incentive frameworks that improve flexibility and encourage innovation and efficiency in electricity network investment.

Network approvals process: The AER

Under the National framework for distribution network planning and expansion, DNSPs must submit a Regulatory Investment Test for Distribution (RIT-D) to the Australian Energy Regulator (AER) for approval to invest in new network assets, and have the cost of those assets reimbursed through customer bills. More recently, this test has been required of DNSPs prior to their investment in network upgrades as well as in the new infrastructure.

“The RIT-D establishes the processes and criteria to be applied by DNSPs in order to identify investment options which best address the needs of the network. It is applicable in circumstances where a network problem exists and the estimated

²⁵ This initiative could apply to any DERs offering the same benefits to the system as smaller-scale CST projects.

²⁶ <http://www.coagenergycouncil.gov.au/publications/coag-energy-council-terms-reference-first-edition-2015>

²⁷ <http://www.coagenergycouncil.gov.au/publications/energy-market-transformation-bulletin-no-05-%E2%80%93-work-program-update>

Australian Concentrating Solar Thermal Roadmap

*capital cost of the most expensive potential credible option to address the identified need is more than \$5 million”.*²⁸

The AER is currently undertaking a review of both the RIT-D process and the RIT-T process, which is the test applied to transmission network service providers (TNSPs) when they seek approvals for infrastructure upgrades.

At this stage of the energy transformation process, the AER could consider further criteria to strengthen the test to support outcomes that are more in line with the proposed outcomes of the transformation process itself. This should require a more stringent examination of options that require DNSPs to support non-network solutions including DER projects and microgrids rather than network upgrades or extensions, where these solutions specifically add value to the security of the system and the reliability of supply thereby providing a cost benefit to consumers.

Market rules: The AEMC

The AEMC is currently looking at arrangements for taking generators off-grid. This includes consideration of additional rules to protect consumers.

*“In September 2016 Western Power submitted to the AEMC a rule change request that would enable DNSPs to provide network services via stand-alone power systems and have those assets/services regulated as though they were part of the interconnected distribution network”.*²⁹

The AEMC concluded that there needed to be a more robust framework to ensure that customers would be protected when taking their electricity supply system off-grid against higher prices and lower levels of reliability. The Energy Council is now developing terms of reference for stand-alone systems and the AEMC will be able to move forward with this process when they are completed.

It can reasonably be expected that this would be resolved within the timeframe required to see commercially viable CST systems developed in line with the modelling for this Report by 2022.

The AEMC process however is not looking at arrangements for supporting DER projects embedded within the network in a way that would incentivise smaller CST systems and other DER installations by transferring the benefits that they add to the system to generators.

Other market subsidies

There are also a range of other sources of income for DER projects within the network system and from state governments that support the operation and security of the grid. These include network support payments, TUOS payments, and in some situations community service obligation payments that could be targeted to non-network solutions such as smaller CST systems. The Energy

²⁸ www.aemc.gov.au/energy-system/electricity/network-planning

²⁹ www.aer.gov.au/publications/submissions/aemc-rule-change-alternatives-to-grid-supplied-network-services

Australian Concentrating Solar Thermal Roadmap

Council could consider how these could be packaged to support DER projects or other activities that produce outcomes in line with the objective of the transformation process.

Summary

In summary, the value that smaller CST systems (and other dispatchable, grid-connected DER projects) can deliver to electricity systems at the fringe of grid, in off-grid locations and to the broader economy clearly justifies the transfer of that value to CST projects. This can be done under the current arrangements where the modelling indicates that CST systems at the fringe of grid make commercial sense from 2022, and where it can be identified that they provide additional system strength values.

This has not yet become a commonplace solution however among DNSPs as it is a departure from the way they have historically developed their networks and been compensated for this development. In fact, the current rules provide a strong incentive for DNSPs to drive additional investment into the network so as to maximise their regulated return.

The authors of this Report recommend that the Energy Council request the EMTPT to work with AEMO, AEMC and AER as a matter of priority to produce a regulatory framework that:

- develops a mechanism that rewards generators located within the distribution network for creating savings by either reducing or avoiding network investment or by adding system strength by enabling these generators to access these savings on a per MW generated basis
- requires DNSPs to proactively support microgrid solutions in fringe-of-grid locations where the test is driven by savings to consumers
- strengthen the powers of the AER to refuse approvals to DNSPs that do not adequately investigate alternatives to grid enhancement, whether below or over \$5 million
- packages other market subsidies to support DER projects or other activities within the distribution network that produce system benefit outcomes in line with the objective of the transformation process
- develops protocols to enable the retail sale of electricity within microgrids, recognising that these will involve monopoly supply situations.

This approach must be commenced as a priority to ensure that these policy, cultural and behavioural changes are made before 2022.

Australian Concentrating Solar Thermal Roadmap

10.2 FOCUS AREA 2: Research, development and early demonstration

10.2.1 ARENA initiatives

10.2.1.1 *Design for manufacture*

As new technologies are developed, the focus is necessarily on effectiveness. As technology progresses through to commercialisation, attention turns toward cost reduction through design. This step is a significant one for technology developers, as it requires expertise that is not typically in-house and requires pragmatism that often challenges passionate inventors and researchers.

ARENA can facilitate and fund independent ‘design for manufacture’ projects for Australian CST technology developers such as Vast Solar, SolaStor and HeliostatSA, where independent specialist design for manufacture teams review designs and look for opportunities including:

- design simplification to reduce component numbers and complexity
- maximising the use of readily available and ‘standard’ products. For example, steel products such as large pipes are made globally in very high volumes to specific specification. Adapting to use these products rather than similar but bespoke products can have a major impact on both cost and availability of components
- applying specialised expertise that is not necessarily available in-house, such as foundation design
- effective volume procurement including leveraging global sourcing resources and improving specification and quality assurance processes
- identifying alternative materials that may provide savings in more general, rather than highly CST-specific, areas. An example of this would be consideration of galvanised mild steel versus stainless or different grades of steel for different purposes.

Funding this process earlier in the commercialisation process can be a cost-effective strategy to capture cost reduction steps earlier and accelerate the early deployment process.

ARENA is currently supporting the development of Vast Solar’s CST technology, which includes novel heat collection and transfer technologies. Support for Vast Solar through a design for manufacture initiative could assist with its mission and the mission of other Australian developers to avoid technical problems and expedite cost curve reductions.

10.2.1.2 *Grant funding for a small number of projects demonstrating Australian CST R&D and intellectual property*

Over the course of the past two decades, tens of millions of dollars have been spent on R&D activities through Australian research institutions including ASTRI, CSIRO, our universities and a small number of Australian-based and owned companies.

Complementing the design for manufacture initiative outlined above, ARENA could consider a higher level of grant funding for project proponents responding to the EOI

Australian Concentrating Solar Thermal Roadmap

processes outlined in Key Focus Area 1 and offer a higher level of support if the projects would assist in commercialising Australian IP and deliver earlier cost curve reductions.

10.2.2 ARENA/ASTRI joint initiative

Initiatives in this section apply specifically to Focus Area 2 but in some instances there will be a cross over with other initiatives where research activities could be undertaken in conjunction with actual project development.

10.2.2.1 Australia Solar Thermal Research Institute

A mid-term review of ASTRI (<http://www.astri.org.au/>) was undertaken in 2016-17. The review indicated ASTRI was undertaking world-leading research and had contributed to Australian capability and capacity. However, the review also noted that ASTRI would need to change if it was to play a key ongoing role in CST in future.

The need for closer engagement with industry and focus on more commercially oriented, real world solutions was highlighted, and has since been responded to, particularly with the establishment of an independent steering committee.

The review also noted ASTRI's contribution to the global effort to research higher temperature system components for CST, which would lead to higher system efficiencies, particularly for smaller (less than 50 MW) systems that are especially relevant to the Australian energy system. This was another area where broader collaboration was recommended, increasing existing collaboration with international research institutions.

An increase in focus on commercial, real world solutions will contribute to accelerating the deployment of both demonstration and commercial systems. The review also recommended additional ongoing funding for ASTRI, a recommendation supported by the authors in tandem with the other recommendations referred to above.

10.2.2.2 Increase collaboration between researchers and industry through improved ASTRI focus

ASTRI is Australia's leading initiative for R&D in the CST sector and is a highly collaborative and successful model with membership from the CSIRO and Australia's most active universities working in the sector. ASTRI is also aligned and integrated with major CST research efforts across the globe, which adds significant value to its own focus.

The Review of ASTRI was conducted by ARENA in 2016-17 for ASTRI's second stage of work produced a number of recommendations that highlighted the need for a greater focus on industry requirements. The authors strongly support this recommendation and understand these initiatives are now being implemented. The inclusion of representatives from international and Australian CST companies, EPCs, developers, market participants and operators within the new ASTRI steering committee is important.

Australian Concentrating Solar Thermal Roadmap

10.3 FOCUS AREA 3: Widespread uptake of CST systems - A contribution to the four Finkel outcomes

10.3.1 ARENA initiatives

10.3.1.1 Underwriting PPAs

Competition in the market is strongly affected by the current concentration of market power in a small number of vertically integrated operators across energy retail, trading and generation sectors. In large part, this is due to the larger entities being the only 'bankable' long-term buyers of electricity in the market, and the result is a natural oligopoly.

Smaller retailers are often unable to enter long-term PPAs and could be assisted if their PPAs were made bankable by external underwriting. ARENA could assist in increasing competition in the market by seeking and working with an underwriting organisation or the CEFC.

ARENA could call for expressions of interest from organisations to underwrite PPAs from smaller retailers, in return for a portion of the generator's PPA revenue. The underwriter could purchase power generated and sell it on the spot market while seeking an alternative off-taker. As PPA prices are almost always set lower than the medium run average wholesale prices, the down side risk of this approach would be low, particularly over a portfolio of projects.

This would encourage the development of new projects, as developers would have more confidence in being able to secure off-takers once projects are completed.

This approach could be very attractive to corporate entities who either want to take longer-term control of their electricity pricing or be associated with green energy projects, enabling significant corporate electricity consumers to enter into direct contracts with specific projects.

A number of finance entities are currently developing similar PPA products or templates for the reasons identified above. ARENA could contribute to developing best practice standards for these products and to increasing sector-wide knowledge to benefit the CST sector as well as the broader renewable energy industry.

10.3.2 Government/regulatory initiatives

10.3.2.1 Reward for time of dispatch

Retailers contracting to purchase electricity via PPAs from dispatchable generators (like CST) should either be encouraged or required to pay a premium for energy delivered during peak times, recognising the value of the energy at this time in the demand cycle. CST developers report that they do not have adequate market power to negotiate bankable PPAs from large retailers that reflect the value of the electricity they could supply into the market at peak times.

This proposal requires further investigation as CST developers report that projects could be commercially viable if there was a closer alignment between peak pricing and the return to the generator at peak times.

Australian Concentrating Solar Thermal Roadmap

AEMO and ARENA could collaborate to run workshops with retailers, generators and project developers to develop strategies that better reward the value of time-of-despatch pricing.

This approach would deliver some of the additional value provided by peak time generation to the generator, over and above their basic PPA pricing.

10.3.2.2 Establishment of renewable energy zones

AEMO's Integrated System Plan (ISP) was released in July 2018 and puts forward the case for renewable energy zones (REZs). Thirty-four potential REZs were identified using a range of factors including a combination of access to renewable resources, access to new or existing transmission facilities, geographic suitability, regional economic benefits and optimum land use considerations.

In addition to identifying suitable REZs, a number of initiatives could be considered to reduce the barriers for DER proponents to invest within the zones, including:

- clear and accelerated path to approvals for network connection
- clear and accelerated process for local and other required government approvals
- local government rates assessment processes that recognise the investment characteristics of electricity generation assets
- access to funding for connection costs for dispatchable RE generators
- access to a zone-specific debt package provided by the CEFC
- specified remediation process for post operation project closure.

This approach would enable network operators, state and local governments and businesses to consider and focus investment in infrastructure, labour, skills and equipment assets in a way that provides optimal utilisation and return. It also removes the current barrier of 'first in pays for the infrastructure' by effectively spreading the support infrastructure costs over the entire zone and a number of projects.

The New South Wales Government has already identified renewable energy zones within the state, but a nationally consistent approach with consistent criteria and organised support for projects within the zones could optimise development costs and customer benefits.

10.3.2.3 Electricity network access

All new generators and storage system providers seeking to enter the electricity grid are faced with the need to negotiate the long, uncertain, opaque and expensive pathway to securing a 'connection agreement' and then meet the costs of the physical connection. This process is a significant barrier to new generation.

A new and more streamlined process could be developed and piloted within one or more REZ before being rolled across the entire network. This process could include:

- standardised, published set of steps
- specified maximum timelines for each step in the process or an aggregate timeline. While some timelines do exist within these processes, they are easily and frequently by-passed

Australian Concentrating Solar Thermal Roadmap

- standard dataset relevant to the proposed project that is to be made available to applicants by network operators, in a standard form and within a maximum time frame
- standard and reasonable approach to funding the application process that is more pay-as-you-go than up-front, due to up front charges often being large and held for years by the network owner as the development process advances.

The above approach would better enable developers to make investment decisions and allow funds to be invested when services are provided, in line with normal business practice if the networks were unregulated, non-monopoly business.

This could also be complemented with streamlined processes for the consideration and processing of development approval applications by local governments in REZs.

10.3.2.4 Three-year notice of closure and AEMO Statement of Opportunities

The modelling undertaken for this Report suggests a strong alignment between the retirement of coal-fired power stations in significant numbers and the commercial competitiveness of CST as the cheapest option for secure and reliable supply of electricity from around 2030.

The Finkel Review recommended a three-year notice of closure for coal-fired power stations to ensure the security of supply. Coordination of this notice with the AEMO Statement of Opportunities would enable CST and other dispatchable system developers to respond in a timely and orderly manner. It would also enable the range of benefits of CST to contribute to an optimal system outcome rather than a series of ad hoc sub-optimal responses to generation and other services lost to the system due to coal retirements.

10.3.2.5 Financial incentives for inertia and system strength

The availability of inertia is not a significant issue today because the predominant generators are turbine-based systems like CST, providing inertia as a default. As the volume of coal-fired generation inexorably declines, inertia will need to be maintained. CST must be available in the market to supply this service.

AEMO could consider establishing a minimum level of inertia with a carrot or stick approach used to ensure it is maintained. This would see new entrants with inertia being rewarded, delivering value where it is created.

10.4 Initiatives for CST industry to consider

10.4.1 Think small to begin with

The Roadmap shows there is up to 1.74 GW of value for the development of smaller CST systems embedded in the network that could be built at no cost to customers.

10.4.2 Target high-value locations

The Roadmap identifies 'low hanging fruit' opportunities for CST in regions and zones where the particular attributes of CST have additional value over and above the supply of energy to the general market.

Australian Concentrating Solar Thermal Roadmap

Opportunities for larger-scale systems (typically 100 MW or larger) are currently limited in Australia due to the need for a confluence of cost reductions, transmission capacity, demand and the solar resource. This will change as some existing generators exit and new transmission emerges, to reflect the decentralising of energy production and new transmission capacity will be established. In the meantime, smaller fringe-of-grid systems can respond to the needs of the network, defer or avoid grid augmentation, increase grid stability and create regional economic growth opportunities.

10.4.3 Consider CHP behind-the meter applications

To date, the CST sector in Australia has in large part focused on the supply of electricity to the market. Success has been achieved in other markets and more recently in Australia with Sundrop Farms by being agnostic to the form of energy provided to a corporate off-taker. In some circumstances, the supply of heat for processing or desalination and electricity provides a better economic return for the project and the off-taker.

10.4.4 Economically optimise configurations

When configuring CST systems, including the size of the solar collector, amount of storage and size of the network connection, consider the value that can be monetised rather than simply the lowest cost achievable. It may be that a higher cost of energy is acceptable if it also drives more revenue for the generator via ancillary services, time of day dispatch, or other incentives that may be in the market or available at a particular location.

The above presents an opportunity for ARENA to provide assistance in the form of information to the CST sector through targeted workshops and presentations to companies. Given that the objective of the Roadmap is to provide a strategy that delivers on the value that CST provides into the energy system in Australia, the modelling undertaken has indicated there is significant value embedded in the network for smaller-scale projects within the next decade. This information can assist the sector in understanding how to overcome commercial and technology barriers to uptake by more cleverly considering the size, location and configuration of plant.

ARENA could hold workshops and presentations for the CST sector to consider these value aspects and highlight the pathway approach to the CST sector. Early projects can be developed if these aspects are built into to project development alongside the second focus area which facilitates the alignment of industry needs with research activities. This will enable the CST industry to deploy existing CST technologies in the 'lower hanging fruit areas' while having a technology evolution pathway focussed on achieving technology improvements and cost efficiencies for a growing deployment into more areas as the technology becomes more competitive.

Towards the end of the next decade, having proved up the technology and its value to the energy system, the third focus area will see the CST sector deploy large-scale projects within the transmission network to replace coal as it exits from the later 2020s and early 30s, primarily on the basis of age. This scale up over time is a lower risk approach given the demonstration and learnings from the earlier deployments in the distribution network.

Australian Concentrating Solar Thermal Roadmap

10.5 Recommendations summary

Key Focus Area 1: Smaller systems connected in the distribution network and off-grid		
Agency	Initiative	Timing
ARENA	<ul style="list-style-type: none"> Grant funding for small number of smaller projects <p style="text-align: center;">*** KEY ROADMAP INITIATIVE ***</p>	2019-2021
ARENA/CEFC	<ul style="list-style-type: none"> A finance 'product' for smaller behind-the-meter CST systems with CHP or potentially just heat 	2019
ARENA/States	<ul style="list-style-type: none"> Heat and power mapping 	2019-2020
Governments / Regulators	<ul style="list-style-type: none"> Transfer network savings value to CST generators <p style="text-align: center;">*** KEY ROADMAP INITIATIVE ***</p>	Urgent
Key Focus Area 2: Research and development		
Agency	Initiative	Timing
ARENA	<ul style="list-style-type: none"> Grant funding for a small number of projects demonstrating Australian R&D and intellectual property 	2019-2021
ARENA/ASTRI	<ul style="list-style-type: none"> Improve collaboration between researchers and industry through Improved ASTRI focus 	Commence 2018
ARENA/ASTRI	<ul style="list-style-type: none"> Increase global research collaboration 	Commence 2018
Key Focus Area 3: Widespread uptake of CST Systems – a contribution to the four Finkel outcomes		
Agency	Initiative	Timing
ARENA	<ul style="list-style-type: none"> Fund design for manufacture for Australian IP 	2019-2020
ARENA/CEFC	<ul style="list-style-type: none"> Underwriting PPAs 	Commence 2019
Governments / Regulators	<ul style="list-style-type: none"> Reward for time of dispatch Establishment of renewable energy zones including streamlined network access processes Electricity network access Three-year notice of closure and AEMO Statement of Opportunities Financial incentives for inertia 	2018-2019 2018-2020 2018-2019 In-train 2025
Industry	<ul style="list-style-type: none"> Consider small options to begin with Target high-value locations Consider CHP behind-the-meter applications Economically optimise configurations 	Now Now Now Now

Australian Concentrating Solar Thermal Roadmap

11 Roadmap timetable

11.1.1 The objective

The objective of the Roadmap is to interrogate the case for the deployment of CST in Australia given its unique range of benefits alongside its relatively higher LCoE and the lack of experience with the technology here.

The alignment undertaken within the Roadmap process, between the modelling, stakeholder views, state of global development, and opportunities for industry development in Australia, suggests a clear pathway forward to commence a steady build.

11.1.2 The two-year plan

The large majority of the proposed initiatives would be most effective if implemented within the next two years. This timing is important as a number of potential smaller projects are in the early stages of development, some in line with the Sundrop Farms combined heat and power project at Port Augusta. Other projects are seeking to use heat alone and others to develop projects that simplify the technology to reduce costs for smaller applications. Other developers such as the ARENA-supported Vast Solar Project at Jemalong in New South Wales are developing new technologies that improve technical and cost efficiencies.

The industry is seeing near-commercial opportunities and the Roadmap provides a sensible pathway for prudent support from this early stage through to full commercialisation and large-scale deployment over the course of the coming decade.

At the end of two years, ARENA could have provided a number of smaller projects with adequate support to have them well underway.

A number of initiatives are also proposed that require action from governments, primarily through the energy portfolio and the regulatory bodies that govern the energy sector. These are prudent initiatives that focus on providing benefits to customers by realising the additional value that CST can offer the energy system, namely making a material contribution to the national challenge to increase system security and the reliability of supply at lowest or no cost to customers. While the initiatives are proposed in the context of a CST Roadmap, most are also applicable to other distributed dispatchable generators.

11.1.3 Five-year plan

Subject to projects in the distribution networks having access to a proportion of the network savings they produce (a key Roadmap recommendation), as well as a small number of smaller projects being deployed with financial assistance, CST will be 'bankable' in fringe-of-grid locations by 2022, allowing self-sustaining deployment to commence.

For this to be achieved, the Roadmap initiatives will:

- increase local industry appetite for, and capability to participate in, the deployment of CST systems
- demonstrate the viability of fringe/off-grid microgrids with CST at the core
- streamline the process for network connection, particularly in REZs

Australian Concentrating Solar Thermal Roadmap

- increase collaboration in research, particularly with local and international businesses in the sector
- increase international interest and investment in CST deployment in Australia through a clear pathway for the sector
- position the CST sector to be able to respond to changes in market factors, particularly the pace of coal exits.

11.1.4 The ten-year plan

The next five years (2018-2023) will see the CST sector prepare for and commence self-sustaining deployment in the fringe of grid. The following five years will see strong deployment and these smaller systems will be the vast majority of CST activity in Australia during the early 2030s when the need for new dispatchable generation and reducing CST costs will drive its deployment.

There are two key sensitivities around the pace and timing of large system deployment:

- the achieved learning curve
- emissions targets.

While any future increases in emissions reduction targets will accelerate the exit of coal-fired generation, the timing and magnitude of changes in targets is not clear at this time. Equally, the authors have decided to work with a conservative learning curve that is more modest than international agencies predict. It would however be imprudent not to prepare for accelerated exits as a result of potential changes in emissions targets and/or faster deployment of larger systems due to lower CST costs.

The modelling suggests that CST will be the lowest-cost solution to meet demand in response to coal exits around 2030. The Roadmap initiatives provide staged support for the gradual deployment of infrastructure in regions and applications that become commercially competitive earliest. The integrated initiatives can assist in moving the CST sector forward to develop a domestic capability that can be expected to provide a significant and material contribution to the orderly transition of the electricity sector as defined by the Finkel Review Team.

Australian Concentrating Solar Thermal Roadmap

11.1.5 Timeline

Responsibility	Focus Area	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Governments/Regulators											
Develop mechanism to transfer network savings	1	Key Roadmap recommendation	Key Roadmap recommendation								
Implement transfer mechanism	1		Key Roadmap recommendation	Key Roadmap recommendation	Key Roadmap recommendation						
Consider inertia incentive	3								In place		
Develop three-year exit notice rule	3	In place	In place								
Establish RE zones	3	In place	In place	In place							
Streamline network access in REZs	3		In place	In place							
Encourage reward for ToD dispatch	3	In place	In place								
ARENA											
EOI for Fringe/Off-grid projects	1		In place	In place							
Grants for Fringe/off Grid	1		In place	In place	In place	In place					
Funding for Design for Manufacture	2		In place	In place	In place						
Funding for demonstration Australian Research/IP	2	In place	In place	In place							
CEFC											
Underwriting PPAs	3		In place	In place	In place	In place	In place	In place	In place	In place	
Funding product for small BTM systems	1		In place	In place	In place	In place					
ARENA/ASTRI											
Improve industry engagement	2		In place	In place	In place	In place	In place	In place	In place	In place	In place
Increase global research collaboration	2		In place	In place	In place	In place	In place	In place	In place	In place	In place
Industry											
Match size to economic opportunities	3		In place	In place	In place	In place	In place	In place	In place	In place	In place
Target high-value locations	3		In place	In place	In place	In place	In place	In place	In place	In place	In place
Consider CHP	3		In place	In place	In place	In place	In place	In place	In place	In place	In place
Economically optimised configurations	3		In place	In place	In place	In place	In place	In place	In place	In place	In place

Key Roadmap recommendation
 In place

Australian Concentrating Solar Thermal Roadmap

Appendices

Australian Concentrating Solar Thermal Roadmap

1. Concentrating Solar Thermal Technology Status – ITP Thermal Pty Ltd

Australian Concentrating Solar Thermal Roadmap

2. Concentrating Solar Power Market Modelling – Energeia Pty Ltd

Australian Concentrating Solar Thermal Roadmap

3. Industry Development Opportunities from Concentrating Solar Thermal Power in Australia - Australian Industrial Transformation Institute

Australian Concentrating Solar Thermal Roadmap

4. Acknowledgements

4.1. Lead contributors:



This Activity received funding from ARENA as part of ARENA's Advancing Renewables Program in addition to ARENA's assistance in facilitation and assistance with access to information and reports from previous ARENA and non-ARENA associated work.

ARENA's lead contributor was Dominic Zaal.



Energeia Pty Ltd performed quantitative analysis to support the development of evidence based, independent, long-term, holistically developed roadmap for Concentrated Solar Thermal (CST) in Australia.

Energeia's lead contributors were Ezra Beeman, Mick Fell and Jacob Kharoufeh.



ITP Thermal Pty Ltd provided information on Australian and international CST cost analysis, technology status, history, industry capacity and potential.

ITP Thermal's work was led by Dr Keith Lovegrove.



The Australian Industrial Transformation Institute (Flinders Business School, College of Business, Government and Law) performed analysis of the opportunities for industry development from the deployment of CST.

AITI's contribution was led by Professor John Spoehr and Associate Professor Giselle Rampersad.

Australian Concentrating Solar Thermal Roadmap

4.2. Stakeholder consultation

JHA would also like to acknowledge the contribution made by the many stakeholders consulted during the development of the Roadmap, including:

- a. Government policy and regulatory bodies
 - i. Department of the Environment and Energy
 - ii. Department of Prime Minister and Cabinet
 - iii. Australian Energy Market Commission
 - iv. Australian Energy Market Operator
 - v. Australian Energy Regulator
 - vi. Energy Security Board
 - vii. Clean Energy Regulator
 - viii. SA Government
 - ix. NSW Government
 - x. Queensland Government
 - xi. Victorian Government

- b. Solar thermal companies, industry bodies, larger energy companies, component providers, finance organisations and major EPCs
 - i. Solar Reserve
 - ii. Vast Solar
 - iii. SolarStor
 - iv. Aalborg
 - v. IES
 - vi. AGL
 - vii. Origin Energy
 - viii. ERM
 - ix. Energy Australia
 - x. Simply Energy
 - xi. Engie
 - xii. Advisian
 - xiii. Cobra
 - xiv. CEC
 - xv. Smart Energy Council
 - xvi. AUSTELLA
 - xvii. SA Power Networks
 - xviii. Ausgrid
 - xix. Transgrid
 - xx. RCR Tomlinson
 - xxi. Diamond Energy
 - xxii. Ausnet
 - xxiii. Acciona
 - xxiv. RES
 - xxv. EnergyQ

Australian Concentrating Solar Thermal Roadmap

- xxvi. HeliostatsSA
- xxvii. NAB
- xxviii. CEFC
- xxix. MUFC
- xxx. The Grattan Institute
- xxxi. Boston Consulting Group
- xxxii. University of Melbourne
- xxxiii. University of Adelaide

Australian Concentrating Solar Thermal Roadmap

4.3. Expert advice

JHA engaged with a wide variety of stakeholders including many energy industry experts. In addition to the joint contributors to this Report (ITP, Energeia and AITI), JHA engaged actively with the market rule maker, regulator and operator.

JHA would like to thank Suzanne Falvi, Executive General Manager, Security and Reliability, AEMC; Craig Oakeshott, Director Wholesale Energy Markets, AER; and David Swift, Advisor to the CEO and EGM Planning and Forecasting at AEMO for their contributions to our process and for making subject experts available to us from within their organisations.

JHA would also like to thank Tony Wood, Energy Program Director at the Grattan Institute and the Hon Robert Hill for their review and advice of this Report.

JHA would also like to thank the many stakeholders from across the energy sector and those sectors relevant to energy who gave their time and expertise to the interrogation process and the Roadmap component of this Report.

Australian Concentrating Solar Thermal Roadmap

5. References

www.environment.gov.au

www.energy.gov.au/government-priorities/energy-markets/independent-review-future-security-national-electricity-market

www.environment.gov.au/climate-change/government/renewable-energy-target-scheme

www.energy.vic.gov.au/renewable-energy/victorias-renewable-energy-targets

www.dews.qld.gov.au/electricity/powering-queensland-plan

www.renewablesa.sa.gov.au

www.resourcesandenergy.nsw.gov.au/energy-consumers/sustainable-energy/renewable-energy-action-plan

www.environment.act.gov.au/_data/assets/pdf_file/0007/987991/100-Renewal-Energy-Tri-fold-ACCESS.pdf

www.climatecouncil.org.au/uploads/9a3734e82574546679510bdc99d57847.pdf

www.coagenergycouncil.gov.au/publications/energy-security-board-update

www.csiro.au/.../Reports/Low-Emissions-Technology-Roadmap

www.aemo.org.au

www.aemc.gov.au

www.aer.gov.au

<file:///C:/Users/susan/AppData/Local/Temp/LowEmissionsTechnologyRoadmap-Technical-Report.pdf>

www.accc.gov.au/publications/restoring-electricity-affordability-australias-competitive-advantage