



Advancing solar in Australia through RD&D investment

November 2016

Final report



Contents

0.	About this report.....	3
1.	Executive Summary.....	3
2.	Context for the report.....	9
3.	Australia’s opportunity in solar energy.....	16
4.	Research priorities to address challenges to accelerating solar energy in the next 10 years.....	21
5.	Research investment models for solar RD&D.....	30
6.	Appendix A– Expert Panel Members.....	46

0. About this report

This report was developed by the Australian Renewable Energy Agency (ARENA) and incorporates commissioned research and ARENA analysis. The report's development was guided throughout by an Expert Panel (see Appendix A). This document forms part of a broader study undertaken by ARENA to refresh its overall investment framework and priorities, which includes reviews of other technologies and programs within ARENA's investment portfolio. The study was undertaken to identify the highest priority RD&D needs to accelerate the competitiveness of solar energy in Australia, and the most efficient approach to investing in RD&D to meet these needs to maximise research outcomes and economic and social returns on this investment.

1. Executive Summary

Federal and state governments in Australia have set a number of emissions reduction and renewable energy targets for the period up to 2030 to help combat climate change and drive an increase in the proportion of Australia's energy mix derived from renewable sources. Solar energy is integral to this effort as, alongside wind, it has the greatest potential to be scaled in Australia in the period of the commitments. However, the growth in solar energy utilisation required to meet these commitments will only occur if there is continued reduction in the cost and efficiency of solar energy; a conducive investment environment for solar energy; and, a broader set of market and technological challenges – such as grid integration - are overcome.

A key lever to accelerate cost and efficiency improvements – and potentially overcome broader challenges - is targeted investment in research, development and demonstration (RD&D) activity. Targeted RD&D can help improve the performance (both efficiency and reliability) of technology; decrease the cost of technology (at the manufacturing, generation, storage, integration, transmission and distribution, and end user stages of the value chain) and – in the later stages – reduce the investment risk of adopting new renewable energy sources by supporting demonstration projects.

Australia's opportunity in solar energy

Solar installed capacity in Australia has grown at 38 per cent over the last four years, rising from 1.4 GW in 2011 to 5.1 GW in 2015. Solar will continue to make a growing contribution to Australia's energy needs over the next decade. While forecasts of the growth in solar capacity vary widely depending on the assumptions adopted, mid-range estimates suggest solar could contribute 15-30 per cent of Australia's total electricity generated in 2030. This implies a total renewable contribution (together with wind and other renewables) of 30-60 per cent in the electricity mix, growing to a significantly higher share thereafter. Over time, solar also has the potential to contribute energy beyond the existing electricity sector to industrial processes, transportation systems and other energy needs.

Achieving these penetration rates would see solar make a major contribution to Australia's climate change and renewable energy targets, including accounting for the vast majority of the installed

renewable capacity required to meet the government's Renewable Energy Target (RET) by 2030 and contributing 11-30 per cent of the government's carbon abatement target gap by 2030.

Solar energy can also make a substantial economic contribution to Australia. Australian researchers have played - and are still playing - a significant role in the development of commercially viable solar energy technologies, going back to the 1960s. Today, Australian research is globally recognised and responsible directly and indirectly for many of the PV technologies currently in commercial production. For solar thermal, applications, Australia is recognised as a world leader in high temperature sodium receivers. Installation, operation and maintenance of solar and related systems could become a major domestic industry. Over time, there is a prospect that solar fuels could be a source of future energy exports.

Research priorities to address challenges to accelerating solar energy in the next 10 years

Australia has promising foundations in place to expand the solar energy industry, but through the consultations undertaken for this study, four critical challenges were identified as constraining the growth of solar energy in Australia. These challenges will need to be overcome to realise the full potential of Australia's solar energy opportunities in the future.

Challenge 1: Further reduction in solar costs and improvement in reliability. The cost of solar PV modules has decreased substantially, making solar PV nearly competitive with wind and cheaper than some of the higher-cost forms of traditional generation. The cost of Concentrating Solar Thermal Power (CSTP) has also fallen over the last decade, albeit at a slower rate than PV.¹ However, both PV and CSTP today remain much more expensive than the presently marginal cost of coal (~3-4c/kWh).² Continuing to reduce costs and improve the quality and reliability of solar electricity generation technologies is critical to increasing the competitiveness of solar within Australia's future energy mix.

Challenge 2: Improvements in the capacity of existing grids to accept intermittent supply sources for solar electricity generation. As solar (and other renewables) contribute a larger share of electricity needs, Australia will need to overcome the challenge of integrating large amounts of solar electricity into existing electricity grid infrastructure.

Public investment should support research to address other emerging challenges further along the value chain, such as grid and integration issues. This needs to be undertaken in a collaborative way that convenes the relevant stakeholders within and outside of the solar industry as the challenges apply to any renewable generation source.

Challenge 3: Identifying and developing attractive new applications. Beyond electricity, greater solar penetration into high-temperature industrial and commercial process heat (over 250 degrees Celsius) and transportation applications, which represent 62 per cent³ of Australian energy demand and 34 per cent of Australian carbon emissions⁴, will present a range of integration challenges. Government funding should also support early stage research into these areas.

¹ AGORA average scenario

² Acil Tasman Assumptions Paper – Modelling of the Australian electricity generation sector

³ Department of Industry and Science – Australian Energy Statistics 2015; Transport, Manufacturing, Mining & Commercial values indicated

⁴ Department of Environment – Emissions Projections 2014; Direct combustion and transport categories indicated

Challenge 4: A supportive regulatory environment. Observations from other markets suggests that an important condition for the rapid growth of solar (and other renewable technologies) is a long-term, supportive and consistent policy and regulatory environment. Experience around the world suggests that financial incentives and regulatory support are typically used to stimulate accelerated solar uptake and reduce the financing risk associated with commercial investment in new technologies. The role of regulatory support is important because the rapid uptake of renewable energy technologies presents a number of challenges to incumbent market participants including traditional generators, grid operators and retailers.

In particular, in a relatively low-growth energy market (as Australia is), a larger and earlier role for significant quantities of solar energy is contingent on the adoption of supporting infrastructure and the decommissioning of excess traditional generation capacity. To reach 30 per cent solar electricity penetration by 2030, an additional 49GW of solar electricity capacity would need to be deployed in Australia.⁵ Around 29GW of this additional capacity may be deployed to meet demand growth and capacity replacement (17GW to meet energy demand growth⁶ and 12GW to replace coal power stations retiring at the end of their useful lives⁷). The remaining 20GW of solar electricity capacity required to meet a 30 per cent target by 2030 would effectively replace traditional generation that is not currently scheduled to retire. However, the effects of bringing forward early retirement of traditional generation are complex and need to be carefully reviewed to understand the full costs and benefits of seeking to stimulate this component of growth of solar electricity, including the impact of policy and/or incentives to facilitate the early retirement of traditional generation and stimulate the deployment of new solar electricity capacity.

Research investment models for solar RD&D

Achieving success in the RD&D priorities described above will require a mix of long term academic research to identify potential step changes in technology and near term commercialisation research to underpin the transition from experimental demonstration to industry adoption. The funding arrangements required for these two types of research are different.

Uncertainty surrounding ARENA's future and funding has significantly constrained ARENA's ability to undertake long-term strategic planning to set investment priorities and to commit to permanent design features in its operating model which support these priorities. Recent confirmation that ARENA will continue as an agency with new investment funding makes it an opportune time to assess how ARENA can ensure it retains the best features of its current approach and operating model, and makes a set of longer term strategic choices about future priorities and operating model optimisation.

ARENA currently uses multiple models for investing in solar RD&D research, including long-term block funding grants to collaborative institutions – which provides multi-year stability funding that

⁵ BREE, AEMO

⁶ Assumes all new electricity growth is met by renewable sources (70 per cent solar and 30 per cent wind). A 21 per cent solar capacity factor was used (obtained from AEMO).

⁷ Based on an assumed 50-year useful life for coal plants (average case provided by the Bureau of Resource and Energy Economics). This implies the retirement of Hazelwood, Anglesea, Liddell, Vales Point B and allerawang).

aggregate effort and funding across multiple, complementary research institutions – and one-off funding allocations for individual projects via open funding rounds.

ARENA's investment approach has many strengths, including the diversity of the slate of projects it has supported and the world-class research outcomes that projects have contributed to; ARENA's generally lean operating model; and ARENA's willingness to take an agile and innovative approach to designing funding rounds and trialling innovative funding instruments.

The review identified opportunities for ARENA to continue to improve its model. ARENA's approach to investing has been iterative and there are opportunities to confirm the practices that have shown to have most effect and to learn from best practice globally.

Future vision advancing solar energy in Australia through investments in RD&D

To help advance solar energy in Australia, ARENA should strengthen and streamline existing investment practices. This would ensure that future investment is directed towards the areas that will have greatest impact for advancing solar in Australia; that there are appropriate and targeted investment models in place suited to the needs of different research stages; and, that the Agency's role is clear and supported by a world-class operating model.

Recommendations for action

Future investment priorities

To maximise the impact of ARENA's solar investment portfolio, research investment should be directed to the research priority areas that match the challenges / opportunities above and build on existing capability. ARENA should prioritise:

- Continued funding for ASTRI and ACAP: Public funding is essential to support the world class academic research in Australia to reduce costs and improve reliability of solar energy. ARENA already funds this research, including through its support for ACAP and ASTRI. Priorities for future funding should include:
 - **PV RD&D needs** – Early-stage research (e.g. low TRL) to foster and build capabilities that will lay the foundation for future PV demonstration and deployment as well as contribute to the necessary long-term technology cost reductions. Research is required to ensure step-change and transformational improvements to efficiency, improved capacity factors, reduced manufacturing and Australian-specific installation costs, and increase lifetime of key system components (e.g. PV modules).
 - **CSTP RD&D needs** – Proving the viability of CSTP technology in Australia through the demonstration and application of CSTP technologies will be critical for the future Australian CSTP industry. Focusing on the commercial application of Australia's world leading CSTP technologies, including high temperature sodium receivers, Super Critical CO₂ cycles / turbines and modular, scalable CSTP systems should be a priority. The commercial viability focus should be on utility scale 50+ MW systems with 6+ hours of storage. Given Australia's thin grid, smaller, scalable, modular and flexible CSTP systems, for remote, industrial or fringe of grid applications may also have a unique role to play in the Australian energy landscape. Over the longer term, CSTP could become more cost-effective as early-research technology advances, especially more efficient small-scale turbines and higher temperature receivers.

- **Challenges in the solar value chain:** Public investment should support research to address other emerging challenges further along the value chain, such as grid and integration issues. This needs to be undertaken in a collaborative way that convenes the relevant stakeholders within and outside of the solar industry as the challenges apply to wind as well as solar. Priorities for future investment could include:
 - ARENA convening generators, grid operators, retailers, regulators, industry associations, researchers, the wind industry and other interested parties to build on existing work to develop a strategy to upgrade grids to accommodate significantly higher levels of intermittent generation.
 - Australian-specific grid modelling, analytics and scenario planning, especially for high-penetration and power ramping, to provide data, transparency and reassurance to Australian market players as well as critical decision making and planning knowledge on the need for greater grid connectivity and new investment in transmission and distribution infrastructure. In addition, a focus on understanding the extent of frequency control and inertia issues will be required (as well as transition pathways) as the Australian grid evolves.
 - The development of new software, innovative market mechanisms and novel grid management approaches, algorithms and optimisation methodologies to assist with Australian grid and system management.
 - Australian demonstration of network-scaled storage solutions which effectively meet electricity demand to build the local market and spread knowledge of these solutions within Australian grid owners, operators and customers. In addition, limited and localised development of smart grid technology and inverters may be required as solar penetration grows.
- **Early stage research:** Selective support for earlier-stage research areas with high potential in the future energy mix. Priorities for future funding could include:
 - **High-temperature industrial process heat** – There is an opportunity to demonstrate the business case for high-temperature industrial process heat in multiple applications and across multiple sectors (e.g. agriculture, minerals processing, food and beverage). Solutions that are especially designed for urban industry may be possible and will be required given Australia’s urban population and industry linkage. Over the longer-term, more research is needed to develop a high-temperature process-heat solution, with a potential link to CST.
 - **Solar fuels** – Over the longer-term, Australia may have a role to play globally in solar fuels, given Australian high DNI and GHI levels, proximity to Asian markets and existing infrastructure for commodity exports. The potential for this market to be large and for Australia to play a role should be explored.
- **Policy and economic research:** Research will not directly impact on the political and socially determined regulatory environment. However, implementing supportive regulatory measures would have greater community acceptance. There may be a role for research on policy questions, including Australian electricity pricing strategies and the operation of the Australian market.

Future investment models

Future investment in the solar RD&D priorities identified in this report will require funding models tailored to the specific needs of both early and later stage research projects. These models should include:

- **An early stage research funding model (e.g. TRLs 2 -4):** subject to the funding available, this could comprise ARC funding; ASTRI and ACAP base funding plus an additional allocation to ASTRI and ACAP; and / or a targeted funding round under the R & D program. This model would ideally be designed with assistance from an independent expert panel made up of non-conflicted senior research directors, industry technical and government representatives. Selection criteria would be weighted towards measures of research excellence, such as the track record of the researchers; potential impact of the research; level of support from the research institutions involved and results from international peer review.
- **A near commercial (demonstration) research funding model:** subject to the funding available, this would include support via the Energy Innovation Fund (EIF), a targeted funding opportunity or opportunities issued via the Australian Research Council (ARC) and / or a Cooperative Research Centre (CRC) or Cooperative Research Centre-Project (CRC-P). This model would be overseen by an industry dominated expert panel. Projects would require any government funding to be matched by some level of industry cash or in-kind contribution and a broader range of non-grant financial instruments would also be considered. Selection criteria would be weighted towards measures of research impact, including the reputation of the researchers, the likelihood of take-up of the outcomes, the potential for protected IP, the soundness of governance arrangements and the level of contribution from non-federal government (particularly industry) resources.

Future investment approach

Confirmation that ARENA has a continuing role and will receive ongoing new investment funding makes it an opportune time for ARENA to confirm the best features of its current approach and operating model, and make a set of longer term strategic choices about its future priorities and operating model. This should include:

- Confirming ARENA's role and core activities within the industry landscape;
- Strengthening a 'six-step' investment approach; and
- Minimising the administrative burden on ARENA and funding recipients.

2. Context for the report

2.1. Purpose of the report

Federal, State and Territory governments in Australia have set a number of emissions reduction and renewable energy targets for the period up to 2030 to help combat climate change and drive an increase in the proportion of Australia's energy mix derived from renewable sources. Solar energy is integral to this effort as, alongside wind, it has the greatest potential to be scaled in Australia in the period of the commitments. However, the growth in solar energy generation required to meet these commitments will only occur if there is continued reduction in the cost and efficiency of solar energy; a conducive investment environment for solar energy; and, a broader set of market and technological challenges – such as grid integration - are overcome.

A key lever to accelerate cost and efficiency improvements – and potentially overcome broader challenges - is targeted investment in RD&D activity. Targeted RD&D can help improve the performance (both efficiency and reliability) of technology; decrease the cost of technology (at the manufacturing, generation, storage, integration, transmission and distribution, and end user stages of the value chain) and – in the later stages – reduce the investment risk of adopting new renewable energy sources by supporting demonstration projects.

This report is an input to ARENA's planning for its future solar RD&D investment decisions. It identifies the highest priority RD&D needs to accelerate the competitiveness of solar energy in Australia, and the most efficient approach to investing in RD&D to meet these needs to maximise research outcomes and economic and social returns on this investment. The work forms part of a broader effort being undertaken by ARENA to refresh its overall investment framework and priorities, which includes reviews of other technologies and programs within ARENA's investment portfolio.

As the Australian Government's primary investment body for renewable energy research, development, demonstration and deployment projects, ARENA is uniquely placed to identify emerging priority future RD&D needs and the most effective investment strategies to support them. Recognising that there are multiple funding bodies operating in this area, the study is intended to help align different funding and policy agencies, research institutions and industry around a common set of priority RD&D needs. This will help coordinate efforts, maximise investment leverage, and ensure that the insights gained from ARENA's experience to date investing in a range of solar RD&D efforts will help strengthen investment priorities and approaches in future.

This report is structured into five sections:

- **Context for the report:** this section explains the purpose and approach of the study; ARENA's role; and the broader policy and economic environment in which ARENA is operating.
- **Australia's opportunity in solar energy:** this section outlines the impact of solar RD&D efforts in Australia to date; and the future opportunity for solar to contribute to Australia's energy transition, emissions reduction target and economic prosperity.
- **RD&D priorities to address challenges to accelerating solar energy in Australia:** this section lays out four critical challenges to advancing solar energy in Australia over the next ten years and the research activity and priorities that can help overcome them.

- **RD&D investment models:** this section provides context to private and public investment in solar RD&D research in Australia; the role of ARENA and other funding agencies; and, ARENA's approach to investment in RD&D.
- **Future vision for RD&D investments to advance solar in Australia:** the final section of the report provides a vision to help advance solar energy in Australia through investment in solar RD&D by laying out future investment priorities for solar RD&D research; potential investment models; and, ARENA's opportunity to institutionalise the best of its investment practices now that its future is confirmed.

2.2. ARENA's role

ARENA was established as an independent agency in 2012 through the *Australian Renewable Energy Agency Act 2011* with the objective of improving the competitiveness of renewable energy and increasing supply of renewable energy in Australia. ARENA was allocated \$2.5B in funding until 2022 to invest in projects and initiatives that hasten the commercialisation of renewable energy solutions and diversify Australia's energy mix. ARENA investments span the commercialisation pathway from research and development to demonstration and near-commercial deployment projects. ARENA takes a technology-neutral approach in considering project applications and has a mandate to capture and share knowledge from its projects. ARENA is overseen by an independent Board.

The projects from nine Australian Government programs were consolidated into ARENA when it first commenced, including those from the Australian Solar Institute and the Australian Centre for Renewable Energy. ARENA produces a General Funding Strategy and Investment Plan each year. This establishes the strategic framework for program development and determines ARENA's investment priorities. Every ARENA project includes a knowledge sharing plan to improve industry capability and streamline the process for delivering renewable energy projects.

ARENA's role in supporting solar RD&D

To help achieve its legislated objective, ARENA invests in solar RD&D activities that are expected to advance renewable energy technologies towards commercial readiness, improve business models, increase collaboration and/or reduce overall costs.

ARENA takes a portfolio approach to investments, supporting activities across the innovation chain from research in the laboratory to large-scale pre-commercial deployment activities. The portfolio includes both innovative technology solutions for earlier-stage activities, commercial models for later-stage solutions and funding for collaborative research institutions, including the Australian Centre for Advanced Photovoltaics (ACAP) and the Australian Solar Thermal Research Initiative (ASTRI).⁸

Solar projects are a major investment area for ARENA. Of the approximately \$922 million⁹ committed by ARENA to renewable energy projects over the last four years, approximately \$288 million has been committed to solar RD&D projects with an additional \$490 million committed to solar projects under the Solar Flagships, Renewable Energy Venture Capital (REVC), Regional Australia's Renewables – Industry (i-RAR) Programme, and Community and Regional Renewable

⁸ ARENA Investment Plan, July 2015

⁹ Unless otherwise stated, all dollar amounts are in AUD; Values from ARENA's Grants Management system as of 30 June 2016

Energy (CARRE) programmes¹⁰ - altogether around 85 per cent of ARENA's total committed investment to date.

Solar PV and CSTP technologies have received a high proportion of the overall investment in solar. This reflects ARENA's historical focus on increasing generation from, and cost competitiveness in, solar; Australia's world-leading capabilities in these areas; and, ARENA's support for two significant collaborative research initiatives, ACAP and ASTRI.

ARENA-funded projects have achieved considerable impact, including entrenching Australia's world-leading solar research capabilities, achieving new world records in solar efficiency, generating 142 patents and supporting nearly 1,000 research positions.

ARENA's future role

In September 2016, the Australian Parliament passed legislation concerning the future funding profile of ARENA. As a consequence, the agency now has \$800 million in available grant funding to support innovative energy technology until 2022. Importantly, it means certainty for ARENA and the renewable energy sector.

ARENA is working through its revised investment priorities following this development, making it an opportune time to assess how ARENA can ensure it institutionalises the best features of its current approach and operating model, and make a set of longer term strategic choices about future priorities and operating model optimisation.

One consequence of this decision is that ARENA will play three main roles in the future:

- **Portfolio manager:** ARENA has a large existing portfolio of projects to manage—including approximately \$258m in solar RD&D projects and ASTRI and ACAP - and administering the successful projects from the recent large scale solar competitive funding round.
- **Active investor:** ARENA will continue to invest in new research projects, with \$800m in new funding to be allocated to it over the next five years.
- **Advisor and convener:** ARENA has assumed a role as technical advisor role to the Clean Energy Finance Corporation (CEFC) for the newly established EIF, which provides debt and equity investment for clean energy projects moving from the demonstration to commercialisation stage. ARENA has also begun to play a convening role for experimental research activity based on design thinking. Under this approach, ARENA brings together multiple players across an industry or value chain to agree on a set of critical challenges and then a series of short research projects to test innovative solutions to them.

ARENA also has an important knowledge-sharing function, which spans each of these roles.

2.3. Policy and economic context

A series of recent policy developments in energy, climate change and innovation policy make it an opportune time to review ARENA's investment priorities for solar RD&D efforts. Through the Paris Agreement on Climate Change, the Australian government has committed to reduce carbon emissions by 25 per cent - 28 per cent compared to 2005 levels by 2030. The Australian Government

¹⁰ Additional investment of \$490 million committed to solar deployment through various programs: Solar Flagships, Renewable Energy Venture Capital (REVC), Regional Australia's Renewables – Industry (i-RAR), Programme and Community and Regional Renewable Energy Programme (KARRE)

estimates that meeting this commitment will mean that Australia must reduce emissions by approximately 900 MT of equivalent carbon dioxide (CO₂-e)¹¹ in the decade from 2020–2030, and that 200 MT CO₂-e - or 22 per cent of the reductions – will be achieved through technology improvements and other sources of abatement beyond flagship Direct Action measures, such as the Emissions Reduction Fund and Safeguard Mechanism and National Energy Productivity Plan, relating to energy and vehicle efficiency.¹²

The Federal Government has also set a Renewable Energy Target (RET), which requires 33,000 GWh of renewable energy to be generated from large scale, accredited renewable energy sources by 2020 as well as an annual small scale sources (equivalent to 16.95 million MWh in 2016).¹³ In parallel, State and Territory governments have set, or are investigating setting, renewable energy targets, including: the Australian Capital Territory, which has set a target of sourcing 100 per cent renewable energy by 2020; Victoria, which has a target of 20 per cent of energy generated from renewable sources by 2020 and 40 per cent by 2025; South Australia, which has a target of 50 per cent of energy generated from renewable sources by 2025; and Queensland, which is investigating the feasibility of generating 50 per cent of energy from renewable sources by 2030.¹⁴

Looking forward, the Australian Government will review Australia’s emissions reduction policies in 2017 – 2018 and the CSIRO is in process of developing a Clean Energy Technology Roadmap.

Innovation policy

In December 2015, the Federal Government released the National Science and Innovation Agenda. The Agenda is designed to stimulate innovation in Australia, including through increasing collaboration between research bodies and industry and a greater focus on translating research outcomes into productive economic activity. The package included measures to streamline and refocus a greater proportion of research block grant funding toward projects with an industry linkage and introduce ‘clear and transparent measures’ of non-academic impact and industry engagement when assessing university research performance. These measures will be piloted by the Australian Research Council (ARC) in 2017 and fully implemented by 2018. ARENA’s support for research through all TRL stages and via a range of programs and investment instruments means it has built up considerable expertise in incentivising and financing projects with strong industry link and impacts beyond research excellence.

2.4. Study methodology

This study used an analysis of trends affecting solar energy, global best practice approaches to R, D & D investment and a review of ARENA’s portfolio of solar programs to develop a strategic investment framework for future solar RD&D investment. The core elements of the study were:

1. **Identifying global and local solar technology market trends and challenges**, to understand the cost and deployment opportunities as well as the challenges to solar scaling globally; the range

¹¹ This is based on a target of 28 per cent reduction in emissions compared with 2005.

¹² Department of Environment and Energy, *Australia’s 2030 Climate Change Target*, <https://www.environment.gov.au/climate-change/publications/factsheet-australias-2030-climate-change-target>

¹³ Clean Energy Regulator: <http://www.cleanenergyregulator.gov.au/RET/About-the-Renewable-Energy-Target/The-certificate-market/The-small-scale-technology-percentage>

¹⁴ <http://earthresources.vic.gov.au/energy/sustainable-energy/victorias-renewable-energy-targets>;
<http://www.renewablesa.sa.gov.au/>

of potential scenarios for solar's penetration in Australia's energy mix based on solar's technological potential and the Federal Government's current renewable energy and emission reduction policy settings and aspirations; and the challenges and opportunities arising from increasing solar penetration that are unique to Australia.

2. **Establishing best practice approaches to RD&D investment and portfolio management**, including reviewing the approach in comparable countries to assess their solar RD&D priorities and investment levels and to develop a view on effective practices for RD&D investment and portfolio management.
3. **Reviewing ARENA's portfolio of solar programs** to establish how investment has been distributed across different areas; the impact from these RD&D investments, including in addressing solar challenges and developing distinctive capabilities; and what opportunities exist to strengthen the approach to research investment and portfolio management
4. **Developing a proposed future strategic RD&D investment framework and strengthened investment approach** for solar projects that could be supported by ARENA in conjunction with other partner agencies across the Australian Government. This included recommending investment principles and priorities, processes and capabilities required to support the model; and identifying transition considerations, where the approach differed from current practice.

Study scope

The study considered potential RD&D interventions to advance the potential of solar energy in Australia. It considered interventions along the solar electricity value chain (spanning generation, storage, grid infrastructure and integration, end use); the potential contribution of other energy sources (i.e. solar fuels and industrial process heat), as well as enabling RD&D opportunities (e.g. analytics, economic or policy research). The primary focus of the study was identifying the priority areas for future investment, but it also considered the most effective investment models to support these research priorities.

Solar demonstration projects at the pre-commercial deployment stage – some of which ARENA inherited and others of which have been supported by ARENA through the Emerging Renewables Programme or Advancing Renewables Programme – were deemed to be out of scope.

The study did not seek to specify the level of investment that the Australian Government should invest in solar RD&D; rather, the study provided investment scenarios to demonstrate how research funding priorities could be met under a range of investment financing conditions.

Study methodology

The study was informed by:

- **Modelling of Australian solar penetration** to 2030 comparing the levelised cost of electricity (LCOE) and integration costs with the marginal cost of generation to identify the challenges to high-penetration of solar in Australia's electricity generation mix. Inputs to this work included data from multiple reports with forecasts for Australia's installed solar capacity by 2030;¹⁵ historic Australian solar PV installed capacity; historic Australian solar PV installation rates and country-level forecasts of solar electricity installed capacity.

¹⁵ The reports were published by: The Institute for Sustainable Futures; Bloomberg New Energy Finance; Enerdata; the Australian Energy Market Operator; the Bureau of Resources and Energy Economics.

- **Two targeted surveys of experts and stakeholders**, examining challenges and opportunities for solar scaling in Australia and globally; sources of competitive advantage in solar; and the extent and quality of Australian research and industry capability in solar. The first survey was sent to Australian solar and energy experts and stakeholders, and had 72 respondents. The second survey was sent to a select list of global and local experts to seek more detailed input on challenges facing solar globally, and received 30 responses.
- **A literature review of research papers and reports** into solar market trends, solar technologies and projections of Australia’s carbon emissions trajectory and abatement opportunity. Sources reviewed included but were not limited to Bureau of Resources and Energy Economics projections reports, Australian Energy Market Operator (AEMO) forecasting models and analyses, Australian Government Department of Environment emission projections, and tracking reports and publications from the Department of Industry, Science and Innovation’s Office of the Chief Economist.
- **A portfolio level review of ARENA’s investments** in 213 solar projects¹⁶ in the last four years to determine the impact of the investments and the efficiency and effectiveness of the investment and management model, including desktop analysis and review of ARENA project data, core program and investment documents, and interviews with program administrators.
- **Interviews and meetings** with 68 Australian and global solar and RD&D experts, industry experts, government policy-makers and leaders of related renewable energy projects in the Australian Government, including CSIRO’s Low Emissions Technology Roadmap and ARENA’s A-Lab initiative.
- **Interviews with 11 overseas funding agencies and private sector research leaders** on effective practice models for research funding and management.

Stakeholder workshops and site visits

The study team also engaged with approximately 150 additional stakeholders and experts in the course of the project, including researchers, industry members, policy makers, investors, legal advisers, non-governmental organisations and ARENA staff. Stakeholders were primarily engaged through:

- **Six roundtables and workshops** conducted in Adelaide, Sydney, Melbourne, Brisbane and Canberra
- **Five site visits** to solar facilities and research laboratories in Brisbane, Newcastle, Adelaide, Forbes and Sydney.

Expert Panel and Mid-Term Reviews of flagship solar research institutions

An independent, international expert panel of six members provided guidance on the design and content of the study. The expert panel comprised local and global experts in solar technologies, market analysis, research and commercialisation, and was chaired by Dr Bruce Godfrey. **Appendix A** lists the expert panel members and their expertise.

In parallel with this work, independent Mid-Term Reviews were conducted of two flagship Strategic Research Initiatives (SRIs) funded by ARENA, the Australian Centre for Photovoltaics (ACAP) and the

¹⁶ ARENA Grants Management System as of 30 June 2016– RD&D projects only including 86 fellowships, scholarships and international exchanges

Australian Solar Thermal Research Institute (ASTRI). The Mid-Term Reviews were conducted by the expert panel with support from the project team for this study.

The authors are grateful to the Expert Panel and to the many stakeholders and experts who have given their time, knowledge and years of experience to this project.

3. Australia's opportunity in solar energy

Australian researchers have played a significant role in the development of commercially viable solar energy technology, going back to the 1960s.¹⁷ Today, Australian research is globally recognised and responsible directly and indirectly for many of the PV technologies currently in commercial production (see Exhibit 1).

The consequence of technological progress by researchers around the world (including Australian researchers) is that solar has become a mainstream energy source. Over the next two decades when a series of major Australian government emissions reduction and renewable energy targets are due, solar has the potential to make a major contribution to Australia's energy mix, to support the achievement of the government's climate change and renewable energy targets and to become a significant domestic industry and source of export revenue.

Exhibit 1

Australia has built world leading capabilities, delivering global solar records on a range technical outcomes in efficiency and cost reduction

Australia has a proud history of delivering solar research excellence ...

- Global records**
 - Achievement:** UNSW has delivered ~20 global solar records over past 30 years
 - Example:** PERC solar cell technology, first developed in 90s at UNSW, are currently used in 10% of global solar capacity

Recent technical outcomes build on this history ...

- Sunlight to electricity conversion**
 - Achievement:** Increased sunlight to electricity conversion efficiency to 34.4%
 - Who and ARBNA support:** UNSW, with \$1.4m grant
 - Benchmark:** New world record, compared with previous record set by Alta Devices in the US of 24%

- Thin-film solar cell**
 - Achievement:** 7.6% efficiency in a 1cm² CZTS cell (full-sized thin-film solar cell)
 - Who and ARBNA support:** UNSW, under ACAP support
 - Benchmark:** NREL confirmed world leading efficiency

- CST electricity cost reduction**
 - Achievement:** Developed a plant configuration that is expected to achieve 12.9c/kWh at 100MWe
 - Who and ARBNA support:** ASTRI

- Hydrogenation**
 - Achievement:** Patented hydrogenation technology that allow lower-quality silicon to outperform solar cells produced from better quality materials
 - Who and ARBNA support:** UNSW, \$4.4m from ARBNA
 - Benchmark:** Team working with number of world's biggest solar manufacturers to commercialise the technology

... and have contributed to solar penetration:

"Two underlying trends that have contributed to solar power's accelerating growth: exponentially declining costs and rapidly improving efficiency of solar panels"
 —Deloitte, US (2015)

"Higher efficiency is the best way to drive down your balance of system and labor costs"
 —Silevo, US solar cell manufacturer

"Improvement to cell efficiency... is universally recognised as the most important strategy for reducing PV balance of system costs that are increasingly important as module costs continue to decrease"
 —Martin Green (2015)

Source: UNSW website, Solar industry mag., ASTRI annual report (2015); Deloitte (2015) "US solar power growth through 2040"

Supporting Australia's energy transition

Solar installed capacity has grown at a compound annual rate of 38 per cent over the last four years, rising from a cumulative 1.4 GW in 2011 to a cumulative 5.1 GW in 2015 (see Exhibit 2). There is broad agreement that solar will continue to make a growing contribution to Australia's energy needs, however, there are a wide range of views on how high this contribution could be over the next decade. Market forecasts vary widely from 4 per cent¹⁸ to 44 per cent¹⁹ of electricity generation by 2030. This range derives from differences in methodology as well as differences in assumptions,

¹⁷ Following the sun, The pioneering years of solar energy research at The Australian National University: 1970–2005, Robin Tennant-Wood

¹⁸ Bureau of Resource and Energy Economics Bureau of Resource and Energy Economics – Australian Energy Projections to 2049-50
 AEMO 100 per cent renewables study

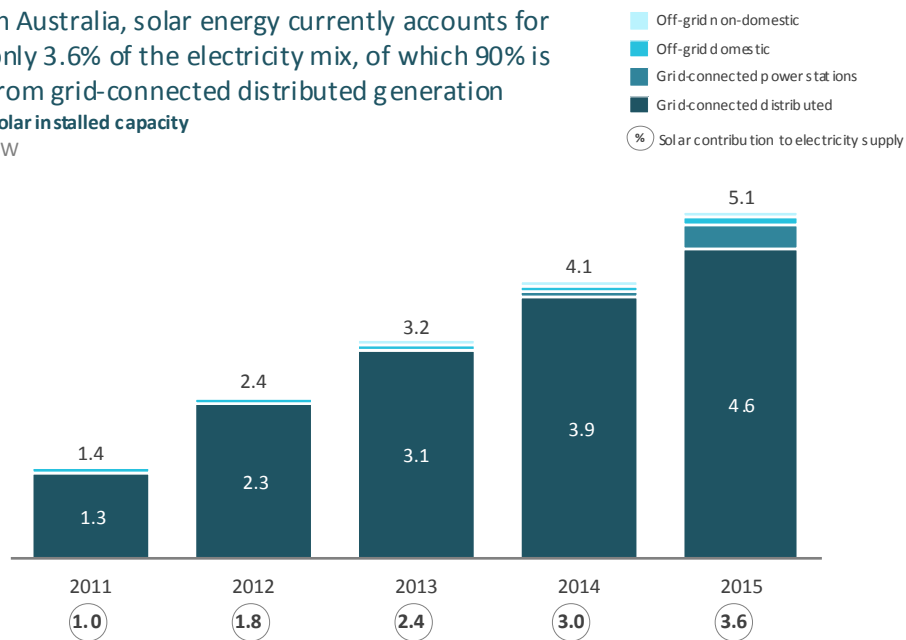
with the higher end of the range involving more aggressive assumptions about costs, financial and policy conditions. While it is not possible to discount the possibility of higher or lower estimates, forecasts near the middle of this range suggest that solar could experience between 12 per cent and 18 per cent compound annual growth rate (CAGR) over the next 14 years, consistent with 15-30 per cent penetration in the electricity mix by 2030 (see Exhibit 3).

Exhibit 2

In Australia, solar energy currently accounts for only 3.6% of the electricity mix, of which 90% is from grid-connected distributed generation

Solar installed capacity

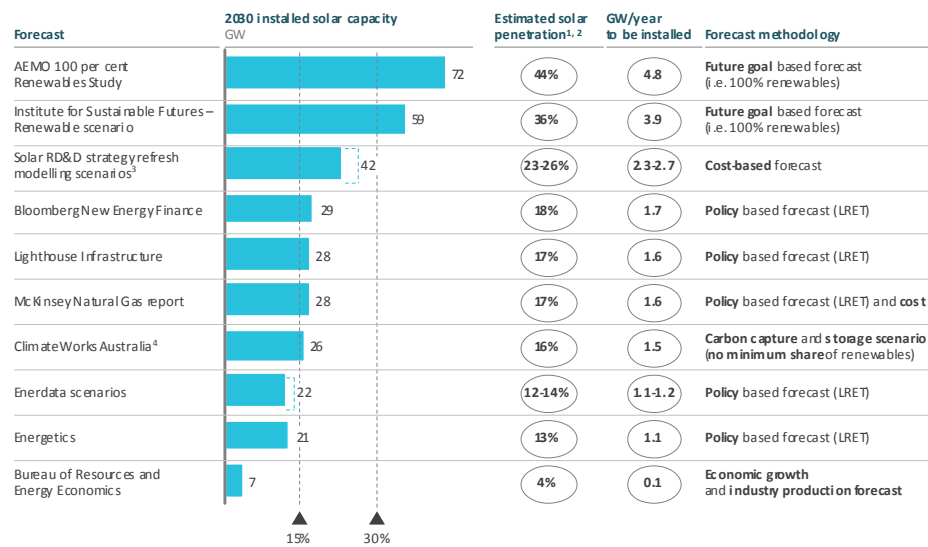
GW



Source: Australian PV Institute, Office of the Chief Economist

Exhibit 3

Mid-range scenarios suggest that solar could contribute 15-30% of electricity generated in 2030 and a significantly higher share thereafter



¹ Estimated penetration based on electricity generation forecast of 299 TWh by 2030 and solar capacity of 21% ² Other renewables such as wind and hydro power will also contribute in addition to indicate solar towards for overall renewable penetration; ³ Modelled scenarios for a low case and high case using LCOE comparative analysis; ⁴ Forecasted electricity generation of 360 TWh by 2030. Estimated solar penetration based on 299 TWh number and 26 GW installed capacity
Source: AEMO, Bloomberg Enerdata, ISF, BREE

These mid-range forecasts would require ambitious increases in the rate of installation of solar generation in Australia. Australia's rate of installation of solar generation capacity would need to rise from 0.9 GW of solar PV per year²⁰ over the last two years to 1.5 GW/year to achieve a 15 per cent penetration and 3.35 GW/year to achieve a 30 per cent penetration by 2030. Although international examples are not entirely comparable as a result of differences in scale, network and policy environments, it is worth noting that California was able to achieve a growth rate of 5.3 GW per year in 2015²¹, and Germany has achieved a yearly growth of more than 7 GW between 2010 and 2012 and 4.0 GW between 2013 and 2015 (Refer to Exhibit 4 for additional information).²²

²⁰ Average of additional solar PV installed capacity per year for 2013-2015, delivered under generous policy conditions

²¹ IRENA, Renewable Energy Costs, 2015 & GlobalData

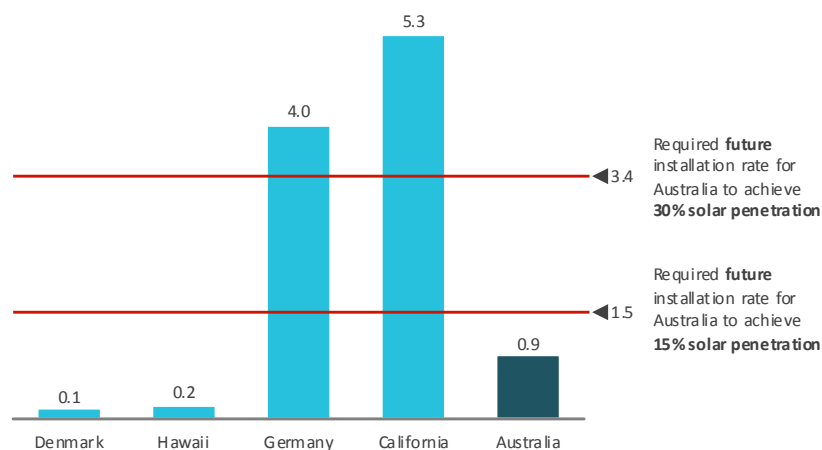
²² FhG ISE: Aktuelle Fakten zur Photovoltaik in Deutschland 22.4.2016

<https://www.ise.fraunhofer.de/de/veroeffentlichungen/veroeffentlichungen-pdf-dateien/studien-und-konzeptpapiere/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf>

Exhibit 4

The implied Australian growth rate to reach 15-30% solar penetration in the electricity mix is challenging but achievable based on global historic solar installation rates

Installation rates of solar PV¹
GW/year



¹ Average of additional solar PV installed capacity per year for 2013-2015
Source: GlobalData

Beyond the electricity sector, solar also has the potential to play a substantial role in other parts of Australia's energy system, including industrial processes and transportation. Solar energy's role in these areas will depend on technical progress²³ and commercial viability.²⁴

Achieving Australia's emissions objectives

If solar were able to contribute 15-30 per cent of the electricity mix by 2030, it would make a major contribution to Australia's renewable energy and climate change targets.

A range of renewable energy technologies will contribute to this growth, with solar expected to account for around 60-70 per cent of the total increase in installed renewable capacity over this timeframe. Estimates for wind energy capacity forecast a rise from 4 GW in 2015 to 37 GW in 2030 – delivering around 13 per cent of total electricity mix.²⁵ Hydro installed capacity is expected to stay constant between 2015 and 2030 at 8 GW – delivering around 6 per cent of total electricity mix in 2030. Other renewable energy technologies are expected to have lower long-term potential than solar due to geographical, environmental, technical and economic constraints.

Solar has the potential to contribute meaningfully to the Australian government's climate change commitment to reduce emissions by 26-28 per cent below 2005 levels by 2030.²⁶ If solar were able to contribute of 15-30 per cent of the electricity mix by 2030, it would deliver a reduction of 32-86

²³ Solar is likely to have most success in low/medium temperature industrial heat processes, which may be suitable for replacement with CST. High temperature industrial heat processes will require further technical progress to overcome challenges of intermittency and intensity.

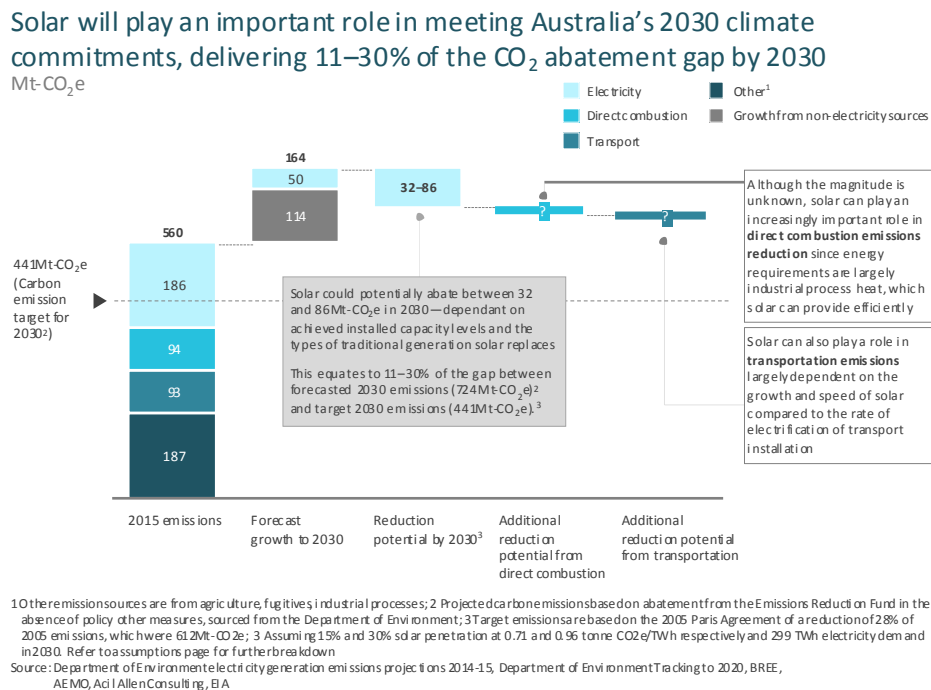
²⁴ The role of solar in medium-to-high temperature industrial process heat is challenged by a lack of significant demonstrated successes.

²⁵ UTS – 100 per cent Renewable energy in Australia report

²⁶ Department of Environment – Australia's 2030 climate change target

Mt-CO₂e between now and 2030 after accounting for forecast growth.²⁷ Further abatement could be delivered as solar contributes over time to industrial processes, transport and other parts of the energy system. Exhibit 5 provides additional information on the abatement opportunity from solar energy in Australia.

Exhibit 5



Future economic opportunities

Australia has abundant solar resources, with annual solar radiation falling on Australia of approximately 58 million petajoules, approximately 10,000 times Australia's annual energy consumption.²⁸ The Australian continent has both high DNI of 6.22 kWh/m²/day on average (the highest of any continent) and high GHI of 5.77 kWh/m²/day on average (second only to Africa).²⁹ Solar energy is already a major source of innovation, education and research activity in Australia, attracting students, researchers and investment from overseas. Australia's long-established and world-leading R&D capability in a number of solar and complementary technologies has, and continues to produce, intellectual property, skilled people, and commercial innovations in equipment and analytics software that have been adopted in local and global supply chains. ARENA funded projects alone have led to 140 patents, more than 800 peer-reviewed journal articles (including >20 papers from ACAP in top 1 per cent of their field), and demonstration in Australian research laboratories of world-leading solar resource conversion technologies. These capabilities are already underpinning the creation of new companies, jobs and export opportunities in Australia

²⁷ Emissions in 2005 were 612Mt-CO₂e and this is expected to rise to 724 Mt CO₂e. Carbon emissions based on abatement from the Emissions Reduction Fund in the absence of policy other measures. Department of Environment, BNEF, Office of the Chief Economist.

²⁸ ARENA Australian Energy Resource Assessment – Chapter 10

²⁹ Meteorm and SolarGIS

which will grow significantly over time. ARENA has supported the commercialisation of research and facilitated the development of research-industry partnerships, for example:

- **Trina Solar**, a Chinese company founded in 1997, is a partner in ACAP projects and has worked with ANU to develop high-efficiency IBC solar cells – a technology now in mass production.
- **Fulcrum 3D** received ARENA support to develop ‘CloudCAM’ which uses remote sensors to monitor solar and cloud events. These systems have been installed in Australia as well the UK, US and other markets.
- **Solar Analytics**, creators of software for household energy system monitoring, was a spin-out from the solar PV research and industry. Solar Analytics provides consumer-oriented dashboard software and an associated Solar-Smart Monitor.

Solar-derived energies are poised to become major industries in the next few decades and Australia has the potential to benefit from those industries’ growth. For example, considerable additional jobs could be created in Australia from the construction, operation and maintenance of solar electricity installations and related industries.³⁰

Over the longer term, solar energy may have the potential to form the basis for an export industry focused on solar fuels in the form of hydrogen and hydrocarbons. Solar fuel technologies use concentrated solar radiation to store solar energy in a chemical form for subsequent use for purposes such as transportation, electrical power generation and on-demand production of industrial process heat. In a future energy mix that is increasingly supplied by otherwise variable renewable energy, solar fuels offer high-density energy storage that can be used as a long term store of energy (overcoming daily intermittency) and that can be transported over long distances from point of capture to point of use (overcoming seasonal variability).³¹ Solar fuels have the potential to contribute the greenhouse gas abatement in sectors such as transport, currently the fastest growing source of emissions in Australia.

4. Research priorities to address challenges to accelerating solar energy in the next 10 years

With the growth in demand for solar energy in Australia and internationally, together with an excellent existing research base there is an outstanding opportunity to expand the solar energy industry. But through the consultations undertaken for this study, four critical challenges were identified as constraining the growth of solar energy in Australia. These challenges will need to be overcome to realise the full potential of Australia’s solar energy opportunities in the future:

- **Challenge 1:** Further reduction in solar costs and improvement in reliability
- **Challenge 2:** Improvements in the capacity of existing grids to accept intermittent supply sources for solar electricity generation

³⁰ Source: Climate Council (2016) Renewable energy jobs: Future Growth in Australia, Renew Economy, SolarGIS

³¹ CSIRO, Concentrating Solar Fuels Roadmap: Final Report

- **Challenge 3:** Identifying and developing attractive new applications such as solar fuels, transport and industrial heating
- **Challenge 4:** A supportive regulatory environment

The main focus of government-funded research should continue to be reducing costs and increasing reliability of solar energy (i.e. Challenge 1). There is also a role for research in improving grid integration (Challenge 2), although this challenge will require a combined effort by all players including generators, grid operators, retailers and regulators. In addition, government funding should also support early stage research into areas with high potential for the future such as solar fuels, transport and industrial process heat (Challenge 3). Research will not directly impact the regulatory environment (Challenge 4), other than the indirect impact that falling solar energy costs will have on community acceptance of solar power.

Challenge 1: Further reduction in costs and improvement in reliability

Continuing to reduce costs and improve the quality and reliability of solar electricity generation technologies is critical to increasing the competitiveness of solar within Australia's future energy mix.

The cost of solar PV modules has decreased substantially, making solar PV competitive with wind and cheaper than some of the higher-cost forms of traditional generation. The cost of CSTP has also fallen over the last decade, albeit at a slower rate than PV.³² The current LCOE of solar PV electricity generation in Australia is ~9c/kWh³³, excluding soft costs and connection costs.³⁴ When storage is required as an accompanying technology and sized to deliver baseload, it can push the combined costs up to ~50c/kWh³⁵ excluding grid integration. The LCOE of CSTP is ~12 - 15c/kWh³⁶ which typically includes storage costs with integrated thermal storage units. Both PV and CSTP remain much more expensive than the marginal cost of coal (~3-4c/kWh).³⁷ (Refer to Exhibit 6 for additional information).

Over the long term, solar and storage costs will need to fall to ~3-4c/kWh marginal generation costs³⁸ to be competitive with the current fossil-fuel based sources of Australian electricity.

Lowering these costs, and enhancing value, will require significant improvements in several areas:

- **Efficiency** – including technical advancements supported by basic and commercial research to improve efficiency and reduce the cost of manufacturing.
- **“Soft” costs** – including reductions in installation, approval and other costs.

³² AGORA average scenario

³³ It is recognised that LCOE is impacted by a range of factors, of which RD&D is one. Accordingly, there may not always be a direct correlation between RD&D activity and LCOE in Australia and reductions in LCOE may not be the best measure of RD&D effectiveness. Further, LCOE varies by market (and is higher in Australia), as it is influenced by local factors - such as the level of subsidisation.

³⁴ ARENA 2016 Large Scale Solar PV application data

³⁵ IRENA 2016 & ARENA 2016 Large Scale Solar PV application data, Lazard – Levelised Cost of Storage Analysis Version 1.0

³⁶ AFR (2015) “Solar industry still waiting for time in the sun”; expert panel advice

³⁷ Acil Tasman Assumptions Paper – Modelling of the Australian electricity generation sector

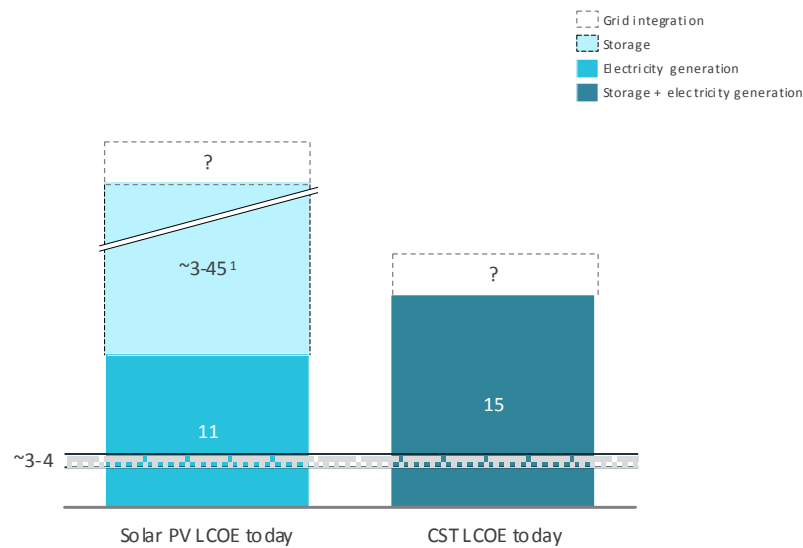
³⁸ To be competitive, the full cost to build new solar generation, ensure its dispatchability, connect it to the grid (e.g. if not distributed) and operate and maintain must compete with the costs to operate traditional generation – given build and grid connection costs are already ‘sunk’ – this is how generators will view the business case

- **Reliability and lifetime** – including increased reliability and lifetime of critical system components (e.g. PV modules), which reduce maintenance costs and increase the useful life of infrastructure.
- **Storage and integration** – including reducing the LCOE of decentralised and network-scale storage while ensuring cost-effective integration into electricity grids and other energy processes.

Exhibit 6

Challenge 1: Costs must continue to come down across the value chain so that solar can replace coal—which has a marginal cost of ~4c/kWh

c/kWh (A\$)



1 Cost range highly dependent on storage technology utilised (e.g. pumped hydro vs. thermal vs. battery)
Source: IRENA (2016), ARENA (2016) Large Scale Solar PV application data, AFR (2015) "Solar industry still waiting for time in the sun", Lazard – Levelised Cost of Storage Analysis Version 1.0

Research priority recommendation: Public funding is essential to support the world class academic research in Australia that assists to reduce costs and improve reliability of solar energy. ARENA already funds this research, including through its support for ACAP and ASTRI. Priorities for future funding should include:

- **PV RD&D needs** – Early-stage research (i.e. low TRL) to foster and build capabilities that will lay the foundation for future PV demonstration and deployment as well as contribute to the necessary long-term technology cost reductions. Research is required to ensure step-change and transformational improvements to conversion efficiency, improved capacity factors, reduced manufacturing and Australian-specific installation costs, and increased lifetime.
- **CSTP RD&D needs** – Proving the viability of CSTP technology in Australia through the demonstration and application of CSTP technologies will be critical for the future Australian CSTP industry. Focusing on the commercial application of Australia's world leading CSTP technologies, including high temperature sodium receivers, Super Critical CO₂ cycles / turbines and modular, scalable CSTP systems should be a priority. The commercial viability focus should be on utility scale 50+ MW systems with 6+ hours of storage. Given Australia's thin grid, smaller, scalable, modular CSTP systems, for remote,

industrial or fringe of grid applications may also have a unique role to play in the Australian energy landscape. Over the longer term, CSTP could become more cost-effective as early-research technology advances, especially more efficient small-scale turbines and higher temperature receivers.

Challenge 2: Improvements in the capacity of existing grids to accept intermittent supply sources for solar electricity generation

As solar (and other renewables) contribute a larger share of electricity needs, Australia will need to overcome the challenge of integrating large amounts of solar electricity into existing electricity grid infrastructure. In this section we first highlight the challenge of intermittency and dispatchability, before reviewing a range of other grid integration challenges to be overcome.

The intermittency (i.e. variability) of some renewable energies is a significant integration challenge as it potentially disrupts the reliability of generation. Solar energy experiences temporal variability at three scales (refer to Exhibit 7):

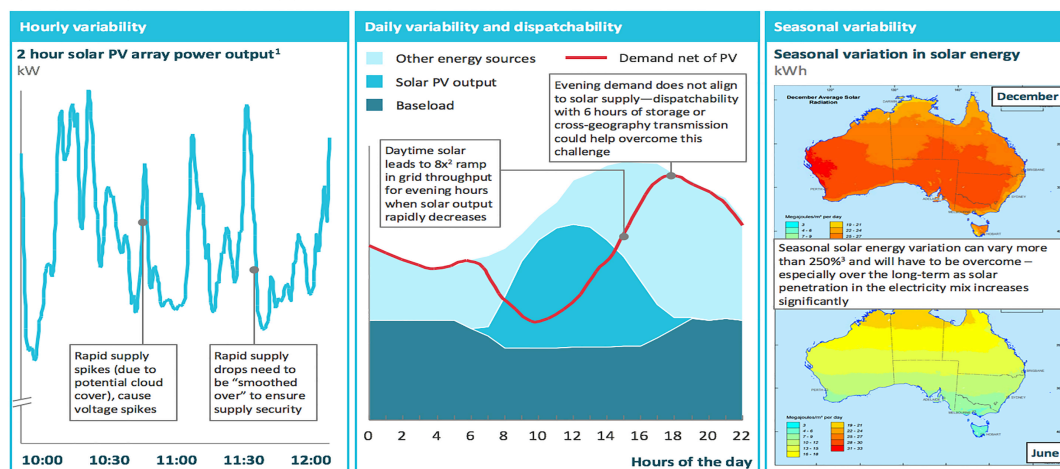
- **Instantaneous** – Clouds are the main reason PV generation experiences high levels of intermittency. PV generation can drop by 60 per cent within seconds due to clouds passing in front of the sun.³⁹
- **Daily** – The rapid decline in solar generation feeding into the grid at the end of the day coincides with a spike in demand for non-solar generation, resulting in significant stresses on the grid.⁴⁰
- **Seasonal** – Monthly average solar radiation can vary by more than 250 per cent (December versus June)⁴¹, depending on location.

³⁹ ³⁹ Based on UQ solar photovoltaic data. June 2013 output: March 14, 2016, 1000-1200

⁴⁰ Energex Distribution Annual Planning Report – 2014/2015 to 2018/2019 – Figure 57

⁴¹ Based on UQ solar photovoltaic data. June 2013 output: 89kWh; December 2013 output: 255kWh

Challenge 2: Australia will need to cope with the time-variability of the solar resource



1 Brisbane actual solar output 14 March 2016
 2 Energex Distribution Annual Planning Report—2014/2015 to 2018/2019—Figure 57
 3 All sites data, June 2013 (89kWh) vs. December 2013 (255kWh)
 Note: Additional supporting materials in appendix
 Source: IEA; UQ Solar Photovoltaic Data

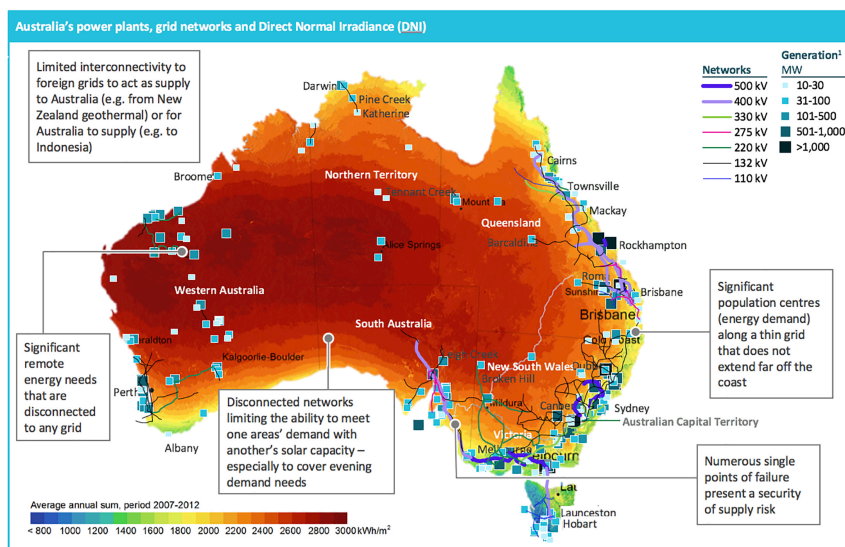
Over the medium term, as solar electricity penetration increases, Australia will need to address the dispatchability and the mismatch in timing between solar generation and demand. Variation in solar generation at both a daily usage level and through the year will likely require greater balancing capacity, behavioural change (e.g. demand management) and systematic solutions at local and grid scales (e.g. storage on multiple scales and short-term cloud cover prediction).

In addition to intermittency, as solar (and renewable energy more generally) comprises a larger share of Australia's electricity mix, it will confront a number of technical challenges associated with grid infrastructure integration. The types of grid challenges Australia is likely to experience - and is already experiencing in a few locations - as solar penetration rises include:

- **Variable frequency** – Electricity networks run on alternating currents, which are affected by the balance of electricity supply and demand. The NEM requires an electricity frequency of 50Hz. If supply is much greater than demand, frequency increases above 50Hz, and vice versa if supply is much less than demand.
- **Dual flow** – The Australian network has not been designed to support bi-directional power flows. Distributed solar panels which provide electricity back to the grid are problematic for metering.
- **Spatial issues associated with Australia's grid** – Australia has a number of unique geographic challenges (refer to Exhibit 8) including significant remote energy needs that are unconnected to any grid (particularly in WA and NT). Lack of connectivity due to multiple unconnected networks, and no connectivity to foreign grids, present energy supply security risks.⁴²

⁴² Based on information from the Department Industry, Innovation and Science & SolarGIS

Challenge 2: Australia’s geography and existing infrastructure also poses potential spatial challenges



1 Includes both traditional and renewable sources
 Source: Department Industry, Innovation and Science, Solargis.

These grid challenges have already impacted South Australia, which has reached 37 per cent renewable electricity penetration in the last few years.⁴³ As renewable energy has increased, South Australia has come to rely more heavily on its interconnector with Victoria to provide adequate frequency control, power ramping and voltage control. This has come with a series of challenges which will have to be overcome to provide real-life lessons elsewhere in Australia, especially as solar electricity penetration increases.

Research priority recommendation: Public investment should support research to address other emerging challenges further along the value chain, such as grid and integration issues. This needs to be undertaken in a collaborative way that convenes the relevant stakeholders within and outside of the solar industry because the challenges apply to wind as well as solar. ARENA could also convene generators, grid operators, retailers, regulators, industry associations, researchers, the wind industry and other interested parties to build on existing work to develop a strategy to upgrade grids to accommodate significantly higher levels of intermittent generation. Priorities for future investment could include:

- Real-life Australian demonstration of high-penetration systems to identify specific Australian grid and system challenges, alongside associated Australian-specific RD&D needs to help provide reassurance to market players – when international examples and research are not applicable. These demonstrations may include high-penetration on mini-grids, in communities, on single-lines of the transmission and distribution network, and for whole / larger portions of the Australian grid infrastructure network.

⁴³ The Australia Institute – Power generation in South Australia

- Australian-specific grid modelling, analytics and scenario planning, especially for high-penetration and power ramping, building on the Australian Renewable Energy Mapping Initiative (AREMI), is needed to provide data, transparency and reassurance to Australian market players. It is needed as well for critical decision making and planning knowledge on the need for greater grid connectivity and new investment in transmission and distribution infrastructure. In addition, a focus on understanding the extent of frequency control and inertia issues will be required (as well as transition pathways) as the Australian grid evolves.
- The development of new software, innovative market mechanisms, novel grid management approaches, algorithms and optimisation methodologies to assist with Australian grid and system management.
- Australian demonstration of network-scaled storage solutions which effectively meet electricity demand, to build the local market and spread knowledge of these solutions within Australian grid infrastructure. In addition, limited and localised development of smart grid technology and inverters may be required as solar penetration grows.

Challenge 3: Expanding solar research to new applications such as solar fuels, transport and industrial heating

Beyond electricity, greater solar penetration into medium-to-high-temperature industrial and commercial process heat and into transportation applications, which represent 62 per cent⁴⁴ of Australian energy demand and 34 per cent of Australian carbon emissions⁴⁵, will present a range of integration challenges (see Exhibit 9).

In many cases, investment will be required to integrate solar energy with existing industrial and transport infrastructure. Even though the return from this investment can meet hurdle rates (as evidenced by successful projects), certain projects still have to contend with on-going financial challenges (e.g. high risk premiums from financial institutions), operational challenges (e.g. the need for security of heat supply and business continuity, and the preference for businesses to wait for end of life on existing assets), technical challenges (e.g. the need to deliver high-temperature solutions for a significant set of energy consuming processes) and management challenges (e.g. the absence of precedent projects).⁴⁶

There are also a range of challenges associated with the solar fuels value chain (e.g. conversion efficiency, cost effectiveness, transportation and infrastructure) which need to be tackled. Addressing them is important as solar fuels could become a major application for solar energy as well as a potential pathway for solar integration into other value chains.

⁴⁴ Department of Industry and Science – Australian Energy Statistics 2015; Transport, Manufacturing, Mining & Commercial values indicated

⁴⁵ Department of Environment – Emissions Projections 2014; Direct combustion and transport categories indicated

⁴⁶ ITP report – Renewable energy options for Australian industrial gas users

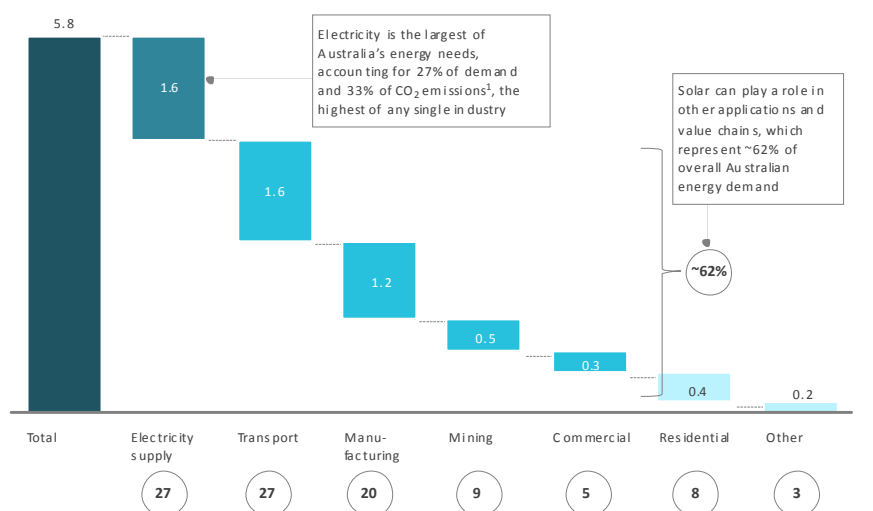
Research priority recommendation: Public investment should continue to selectively support earlier-stage research areas with high potential in the future energy mix. Priorities for future funding could include:

- **Industrial process heat** – There is a near-term opportunity to demonstrate the business case for industrial process heat in multiple applications and across multiple sectors (e.g. agriculture, minerals processing, food and beverage). Over the longer-term, more research is needed to develop a high-temperature process-heat solution, with a potential link to CST.
- **Solar fuels** – Over the longer-term, Australia may have a role to play globally in solar fuels, given Australia’s high DNI and GHI levels, proximity to Asian markets and existing infrastructure for commodity exports. The potential for this market to be large and for Australia to play a role should be explored.

Exhibit 9

Challenge 3: Solar has significant potential to contribute to Australia’s energy needs beyond electricity

EJ (Exajoules) in 2013-14



1D Department of Environment, electricity generation emissions projections 2014-15
Source: Department of Industry and Science (2015) Australian Energy Statistics

Challenge 4: A supportive regulatory environment

One of the most important conditions for the rapid growth of solar (and other renewable technologies) is a supportive and consistent policy environment. Observations from other markets suggests that financial incentives and regulatory support are typically used to stimulate accelerated solar uptake and reduce the financing risk associated with commercial investment in new technologies.

These observations suggest regulatory support is important because the rapid uptake of renewable energy technologies presents a number of challenges to incumbent market participants including traditional generators, grid operators and retailers. In particular, in the relatively low-growth energy market of Australia, a larger and earlier role for significant quantities of solar energy is contingent on

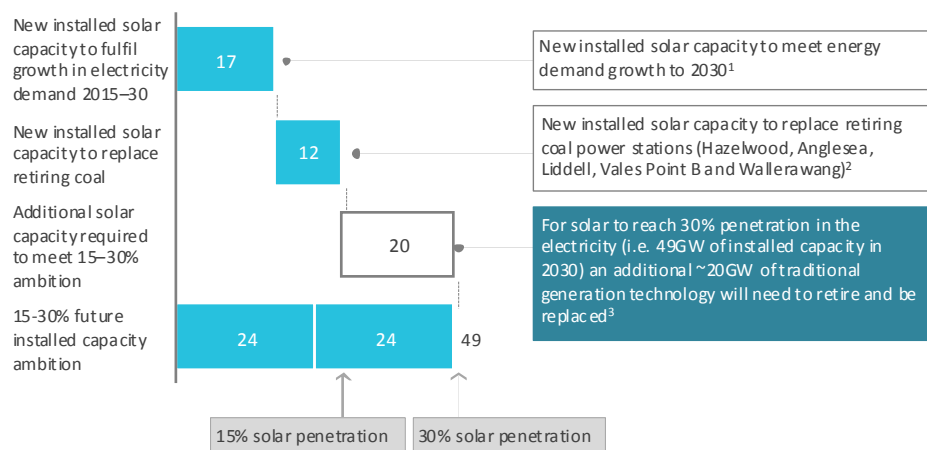
the adoption of supporting infrastructure and the decommissioning of excess traditional generation capacity. To reach 30 per cent solar electricity penetration by 2030, an additional 49GW of solar electricity capacity would need to be deployed in Australia.⁴⁷ Around 29GW of this additional capacity may be deployed to meet demand growth and capacity replacement (17GW to meet energy demand growth⁴⁸ and 12GW to replace coal power stations retiring at the end of their useful lives⁴⁹ – refer to Exhibit 10).

The remaining 20GW of solar electricity capacity required to meet a 30 per cent target by 2030 would effectively replace traditional generation that is not currently scheduled to retire. The effects of bringing forward early retirement of traditional generation are complex and need to be carefully reviewed to understand the full costs and benefits of seeking to stimulate this component of growth of solar electricity, including the impact of policy and/or incentives to facilitate the early retirement of traditional generation and stimulate the deployment of new solar electricity capacity.

Exhibit 10

Challenge 4: Australian energy markets may need to incentivise early retirement and/or reward rapid up-take of solar technologies

Future solar installed capacity (2015–30); GW



¹ Assumes all new demand growth from 2015-30 met by renewable sources with a 70% solar, 30% wind, and 21% solar capacity factor
² Assumes a schedule for coal plant retirement after 50 years of operation, 50-year useful life is the average case given by Bureau of Resource and Energy Economics
³ Does not account for gas retirement, given the importance of gas to provide peaking capacity
 Source: Bureau of Resource and Energy Economics, Acil Allen Consulting, AEMO

Research priority recommendation: Research will, in general, not directly impact on the political and socially determined regulatory environment. However, by reducing the impact solar energy will have on energy prices or the need for subsidies, implementing supportive regulatory measures would have greater community and therefore political acceptance. There may be a limited role for policy and economic research on policy questions. Potential research priorities for

⁴⁷ BREE, AEMO

⁴⁸ Assumes all new electricity growth is met by renewable sources (70 per cent solar and 30 per cent wind). A 21 per cent solar capacity factor was used (obtained from AEMO).

⁴⁹ Based on an assumed 50-year useful life for coal plants (average case provided by the Bureau of Resource and Energy Economics). This implies the retirement of Hazelwood, Anglesea, Liddell, Vales Point B and Wallerawang).

the future could include support for policy research to understand Australian electricity pricing strategies, Australian market price mechanisms, and component ownership and control structures.

5. Research investment models for solar RD&D

5.1. RD&D investment environment for solar in Australia

Supporting the RD&D priorities described in the previous section will require a mix of long term academic research to identify future potential step changes in technology and near term commercialisation research to underpin the transition from experimental demonstration to industry adoption. The funding arrangements required for these two types of research are different. This chapter considers different investment models for supporting priority solar RD&D needs, including the current and future role of ARENA in the Australian research investment environment, and makes recommendations for ARENA's future model for solar RD&D investments.

Solar RD&D investment in Australia

Australia undertakes world class academic research in solar, which is predominantly publicly funded. Australia has some success in near term commercialisation research, albeit more limited, largely due to the small size of the solar industry in Australia. While industry support for solar RD&D is important to encourage the translation of research outcomes into commercial and economic benefits and to see a return on the investment government has made, publicly-funded investment in solar RD&D will continue to be necessary to support priority solar efforts where:

- **The timeframe to realise the benefits of the research is too long or uncertain to be attractive to industry:** support for basic and early stage RD&D (e.g. TRL stages 1-5) is typically via publicly-funded research grants because returns from investment in these types of projects are long term and uncertain, and therefore unlikely to produce a commercial return within a period attractive to non-government investment sources. Investments in later TRL stage RD&D are more likely to produce concrete commercial returns, and can typically be supported by a broader range of financial instruments and matched funding, in addition to grants.
- **The industry in Australia is too small or nascent to invest in RD&D:** for example, there is almost no PV cell manufacturing in Australia and the industry is not profitable world-wide so the industry has limited resources to invest in research. Further, since the 1970s, grid-connected solar PV has been marked by 'boom and bust' industry behavior. Industry growth has been driven by government incentives, which are unreliable in the long-term in their design and longevity. This has created a global industry which is incentivised to 'chase' the demand generated by incentives before they expire or are changed, even where this means cutting prices and accepting very low margins.⁵⁰ It is likely that the size of the market and the dominance of Asian suppliers will mean Australian company involvement in the silicon PV industry will remain very limited. Solar thermal does present real prospects due to the nature of the technology and the earlier stage of its development.

⁵⁰ SPV Market Research, *The Solar Flare*, June 2015

- **The benefits of the research are spread between a number of parties, none of whom have sufficient individual incentive to act or to collaborate:** issues such as grid integration, which will limit solar (and wind) penetration, require a combined effort by multiple players, including generators, distributors, retailers, and regulators, to address, but no single actor has incentive to solve the issue from a systems perspective.
- **Incumbents have disincentives to invest:** for example, incumbent electricity generators or distributors have already sunk investment into existing plants and network infrastructure.

ARENA funding models

ARENA uses multiple models for investing in solar RD&D research, including long-term block funding grants to collaborative institutions – which provides multi-year stability of funding that aggregate efforts and funding across multiple, complementary research institutions – and one-off funding allocations for individual projects.

Institutional funding

ACAP and ASTRI are long-term collaborative research institutions focussed on solar photovoltaics and concentrated solar thermal research respectively. The collaborative research model is designed to provide an institutional framework for a coordinated, national approach to this research in Australia. By providing a degree of research funding stability to its constituent institutions, ACAP and ASTRI foster systemic national collaboration that links complementary activity at research institutions to deliver jointly agreed outcomes, as well fostering greater international linkages. ACAP has been awarded \$35.914 million in total, while ASTRI has been awarded \$35 million. Funding was provided for a period for eight years, subject to satisfactory performance against agreed milestones and a Mid-Term Review of each program, which was conducted in parallel with this study.

Funding programs

The two funding programs utilised by ARENA for solar R, D & D are:

- **Research and Development Programme:** The research and development programme supports research from early stage through to development. Applications are accepted only in competitive rounds, with two rounds held to date.
- **Advancing Renewables Programme (ARP):** The ARP is an umbrella funding program aimed at demonstration and deployment stage projects (both pilot and large scale). It targets projects that: support activities that reduce the cost or increase the value delivered of renewable energy; advance renewable energy technologies towards commercial readiness; reduce or remove barriers to uptake; or, increase relevant skills, capacity and knowledge. Applications for projects can be accepted at any time. Dedicated competitive rounds can also be created under the program for specified funding opportunities.

Funding instruments

Under ARENA's Act, ARENA is currently able to provide financial assistance in the form of a grant. The Act also allows for other kinds of assistance specified by the Minister by legislative instrument. ARENA is working with other agencies within the Australian Government to publish a new legislative instrument expanding the range of financial instruments it can utilise. These could include:

- **Non-recoupable grants** – These are the most common instrument used by governments to fund R&D.⁵¹ They impose no obligation on recipients to pay back the investment amount allocated and are generally distributed via a competitive application process. Investment is generally released in stages upon achievement of milestones.
- **Recoupable grants** – These are grants that offer a repayment if a certain event occurs. For example, ARENA could require repayment of the grant investment if the project generates a certain level of revenues, or if a major risk is alleviated.
- **Hybrid instruments**, such as:
 - **Convertible notes** – These are grants that allow ARENA to claim equity if ARENA exercises it and has ministerial approval to do so.
 - **Warrants/options** – These instruments impose no obligation on recipients to repay the investment but allow ARENA to participate in any equity upside realised by the project.
 - **Grants with royalty obligations** – The grant investment contract could require the payment of royalties to ARENA from any IP profits obtained as a result of the project for a certain period (or up to a certain dollar amount).

In addition to utilising investment instruments that provide a financial return, ARENA can also require or encourage matched funding, i.e. where the research proponent or industry partners partially fund the work.

The spectrum of commercial returns that ARENA can target with these instruments ranges from a “-100 per cent return” scenario in the case of non-recoupable grants, to a positive return in the case of debt and equity. For lower-TRL projects, a form of grant tied to an articulation of non-commercial benefits and a commitment to sharing in any future financial upside will typically be more practical than debt or equity investment.⁵² Later stage TRL projects (TRL7 onwards) are most likely to be suited to debt and equity instruments.⁵³ Exhibit 11 provides a guide to the types of investment instruments that could be used at various stages of a technology’s or business model’s readiness. It shows that as a project progresses along the TRL stages, the expectation that it should aim to deliver a commercial return increases.

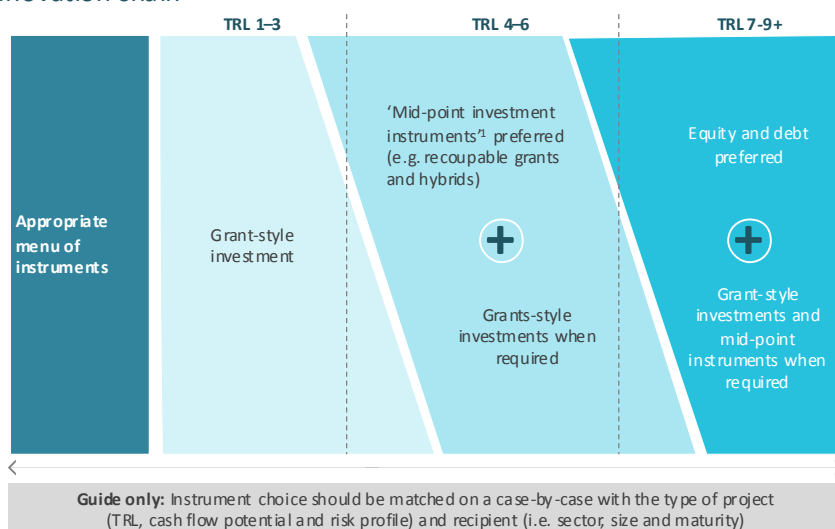
⁵¹ OECD (2014) Technology and Industry Outlook; Bernanke (2011) Promoting Research and Development: The Government's Role, At the Conference on "New Building Blocks for Jobs and Economic Growth", Washington, D.C.

⁵² Pure debt and equity can be overly restrictive and hinder innovation when applied to early-stage research due to the high degree of uncertainty around commercial returns to the researcher. Finding based on interviews with 11 peer agencies and 3 RD&D funding experts.

⁵³ The scenario 3 illustrative investment scenario assumes that the CEIF will be limited to projects from TRL 8 or 9 onwards based on the descriptions of the fund’s purpose being ‘to support emerging technologies make the leap from demonstration to commercial deployment’ (see Department of Environment). There may be projects at TRL stages 7 – 8 that do not fit the description of moving from demonstration to deployment but which would be suited to debt and equity investment based on their potential commercial returns.

The menu of appropriate instruments varies across the innovation chain

ROUGH GUIDE ONLY



1 Mid-point instruments refer to grant-based instruments that allow ARENA to share in any financial upside, or recoversome or all funds if certain conditions are met
Source: Team analysis, based on interviews with 11 peer funding organisations; conversations with ARENA's Business Development & Transactionsteam; OECD Technology and Industry Outlook (2014); Bernanke (2011) Promoting Research and Development: The Governments Role, At the Conference on "New Building Blocks for Jobs and Economic Growth", Washington, D.C.

Other public-funding sources

Outside of ARENA, existing or potential sources of RD&D investment in solar projects are:

- **The Australian Research Council (ARC):** The ARC advises the Australian Government on research matters; administers the \$800m per annum National Competitive Grants Programme; and, has responsibility for the Excellence in Research for Australia (ERA) research quality assessments. The ARC supports some solar-related projects, typically at early research stages (TRLs 1 – 4). Mechanisms include Discovery Grants for purely academic research and Linkage Grants which require an industry or other partner to contribute some level of matching funds.
- **The Clean Energy Finance Corporation (CEFC):** The CEFC exists to stimulate investment in low emissions technologies, including large and small-scale solar, wind and bioenergy. This includes investments via the Energy Innovation Fund (EIF), a debt and equity fund. The CEFC also co-invests with other financiers through climate bonds, equity funds, aggregation facilities and other financial solutions. The newly announced Clean Energy Seed Fund is the first project to be funded through the EIF and will invest in 30 to 50 emerging clean energy start-ups over a 4-5 year period. The fund will focus on discovering and financing emerging innovations and start-ups in clean energy. The \$20 million seed fund will draw on support from the CEFC and ARENA.
- **Cooperative Research Centres (CRCs) programme:** The CRC programme is designed for industry-led, collaborative research efforts, and administered by the Department of Industry, Innovation and Science. The programme has two funding streams: CRCs and CRC-Ps. CRCs support medium to long term industry collaborations for up to ten years and require matching cash or in-kind funding. CRC-Ps support short-term industry-led collaborations for up to 3 years, with funding capped at \$3 million. In broad terms CRCs have been typically funded for 7 years and average about \$70M in total funding (\$10M pa) of which historically 22 per cent has

come from the CRC program, 15 per cent has come from participants cash (university and industry but never CSIRO) and 63 per cent from participants in-kind contributions. The 22 per cent is a mean, low due to some large outliers, and the median per annum government funding would be in the range \$2.5-\$3.0M per annum.⁵⁴

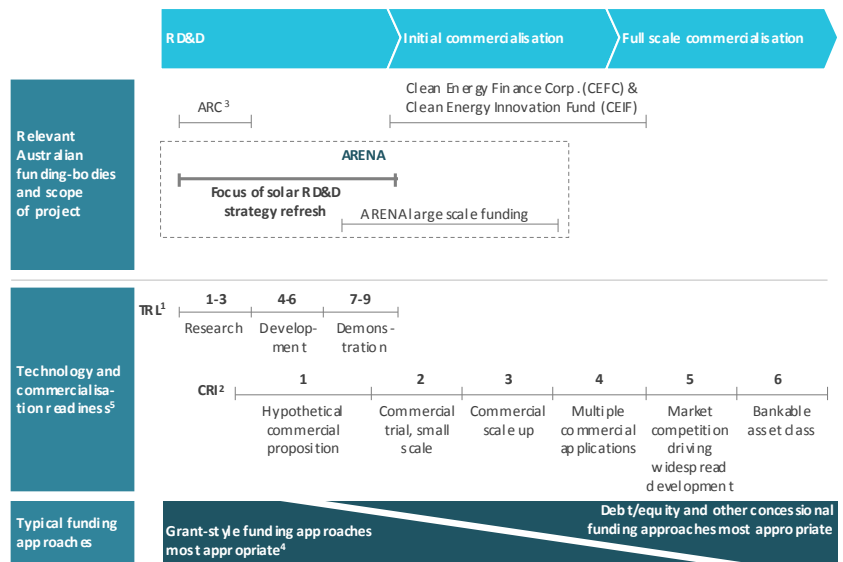
Indirect public funding for solar RD&D also occurs via base funding to universities and the CSIRO.

Roles in the investment ecosystem

The different funding bodies currently play complementary roles in their support for solar RD&D that ensure a healthy pipeline of projects progress along the TRL stages (see Exhibit 12 below). The ARC supports predominantly basic and early stage solar projects (TRL 1 - 3) through one-off research grants to universities. ARENA provides long-term institutional funding for Australia’s two leading flagship solar research institutions – which undertake world-class basic research and some applied research – and provides an important bridging source of research investment for one-off solar projects, predominantly in TRLS 4 – 7/8. The EIF then provides an important new vehicle for projects in later TRL stages, including demonstration and deployment. The newly announced Clean Energy Seed Fund is the first project to be funded through the EIF and will invest in 30 to 50 emerging clean energy start-ups over a 4-5 year period. The fund will focus on discovering and financing emerging innovations and start-ups in clean energy. The \$20 million seed fund will draw on support from the CEFC and ARENA. ARENA’s large scale solar program also provides support for projects in these later stages.

Exhibit 12

ARENA’s RD&D funding is the first step of a continuous pathway to commercialisation of a technology or business model



¹ Technology readiness level
² Commercial readiness index
³ Australian Research Council – currently plays a limited role funding solar RD&D
⁴ In some cases this could include repayable grants or hybrid instruments (explained in Readmen data n.2)
⁵ Refer to ARENA TRL/CRI index classification for more information

⁵⁴ Expert interview <http://crca.asn.au>

5.2. ARENA's future role and funding models for solar RD&D

The Australian Government's confirmation that ARENA will continue as an agency and receive ongoing new investment funding makes it an opportune time for ARENA to institutionalise the best features of its current approach and operating model, and make a set of longer term strategic choices about future priorities and operating model optimisation.

ARENA has historically fulfilled two core roles as an active investor and manager of an existing portfolio. More recently, ARENA has also begun to play an advisory and convening role, for example, by providing technical advice to the EIF and convening multiple players to address grid integration challenges through the A-Lab pilot project. These roles each have unique implications for ARENA's operating model, including the core activities ARENA undertakes, and the resourcing, capabilities, process and organisational design needed to support them. ARENA would benefit from undertaking a series of short, strategic planning exercises to optimise its approach in its traditional roles as a portfolio manager and active investor and to identify, in partnership with stakeholders, the value proposition for its advisory and convenor roles.

Future funding models

ARENA's future investment priorities will require funding models tailored to the specific needs of both early and near commercial research projects (see Exhibit 13). The critical elements in the funding model are:

- **Clearly defined focus of activity:** each model should have a clear link to a set of investment priorities determined by ARENA (for example, the priority research activity identified for TRL stages that map to early stage or near commercial research). This will mean that the model can clearly articulate the priority research areas it is seeking to support, the desired outcomes from the research, and how the effort links back to ARENA's broader strategic goals.
- **Sophisticated and customised investment approach:** For both the early stage and near commercial funding model, ARENA has a set of design choices about the type of investment model it wishes to use, the amount and type of funding it will allocate, and the process and criteria for selection. The approach designed will depend upon the nature of the research intended to be supported and the level of funding needed and available. Exhibit 13 provides an overview of the design choices for investment approaches to early and near commercial research.
- **Expert and independent governance model:** each model should be overseen by independent experts with skills and experience particular to early stage or near commercial research. This could involve creating two mini-panels of experts, building on ARENA's existing expert advisory model. The expert panels should be drawn on through all stages of the investment process, including setting research priorities and outcomes, defining the focus of activity, choosing the most appropriate funding model, developing the amount, type and criteria for funding and reviewing projects once selected.

Funding models should be tailored to early and later stage research needs

ILLUSTRATIVE

		Model A: Early stage research	Model B: Near commercialisation
Focus activity		<ul style="list-style-type: none"> ACAP and ASTRI Early stage research in priority areas, such as solar fuels and process heat 	<ul style="list-style-type: none"> Challenges further along value chain Collaborative approach to network challenges, such as grid integration and intermittency
Investment approach	Model	<ul style="list-style-type: none"> Allocate new investment for early stage research projects (TRLs 1-4) via funding round under R&D program, ARC funding or additional allocation to ASTRI & ACAP Selection criteria based on: <ul style="list-style-type: none"> Track record of the researchers Potential impact of the research Level of support from the research institutions (or CSIRO) Results from international peer review 	<ul style="list-style-type: none"> Allocate investment for near commercialisation (Dev & Dem) projects (TRLs 5-6+) through funding opportunity under ARP, CEIF and / or CRC Selection criteria based on: <ul style="list-style-type: none"> Potential take-up & scale of output Potential for protected IP Soundness of governance set-up Level of contribution from non-fed govt sources, especially industry Researcher/management team
	Commitment length	<ul style="list-style-type: none"> 'Stability' funding (~5-7 yr) to maintain world-class capability in targeted institutions (e.g. ACAP and ASTRI) Avg ~3 year contracts for new projects 	<ul style="list-style-type: none"> Up to 10 years for CRC-style model for potential future collaborative institutes, e.g. for grid integration Avg ~3 year contracts for one-off projects
	Investment instrument	<ul style="list-style-type: none"> Grant-based investment (likely non-recoupable at early stage however with expectations on non-financial outcomes) 	<ul style="list-style-type: none"> Choice of mechanisms, including: <ul style="list-style-type: none"> Matched funding or in-kind Hybrid instruments and recoupable grants
Governance		<ul style="list-style-type: none"> Overseen by independent expert group (non-conflicted senior research directors, industry technical and government representatives) 	<ul style="list-style-type: none"> Overseen by expert group drawn from industry—with mandate to advance industry penetration and returns

Funding model recommendation: Future investment in the solar RD&D priorities identified in this report will require funding models tailored to the individual areas targeted. Two base models from which to start are:

- An early stage research funding model (e.g. TRLs 2 -4):** subject to the funding available, this could comprise ARC funding; ASTRI and ACAP base funding plus an additional allocation to ASTRI and ACAP; and / or targeted funding round under the R & D program. This model would ideally be designed with assistance from an independent expert panel made up of non-conflicted senior research directors, industry technical and government representatives. Selection criteria would be weighted towards measures of research excellence, such as the track record of the researchers; potential impact of the research; level of support from the research institutions involved and results from international peer review.
- A near commercial (demonstration) research funding model:** subject to the funding available, this would include support via the EIF, a targeted funding opportunity or opportunities issued via the ARC and / or a CRC or CRC-P. This model would be overseen by an industry dominated expert panel. Projects would require any government funding to be matched by some level of industry cash or in-kind contribution and a broader range of non-grant financial instruments should also be considered. Selection criteria would be weighted towards measures of research impact, including the reputation of the researchers, the likelihood of take-up of the outcomes, the potential for protected IP, the soundness of

governance arrangements and the level of contribution from non-federal government (particularly industry) resources.

5.3. ARENA's approach to solar RD&D investment

The study undertook a program level review of ARENA's approach to investment, and compared ARENA's approach with the practices of 11 peer funding bodies globally. The review found that ARENA's investment approach has many strengths, including the diversity of the portfolio of projects it has supported and the world-class research outcomes that projects have contributed to; ARENA's generally lean operating model; and, ARENA's willingness to take an agile and innovative approach to designing funding rounds and trialling innovative funding instruments. There is also evidence that ARENA's approach to investment and funding model design has become increasingly sophisticated over time.

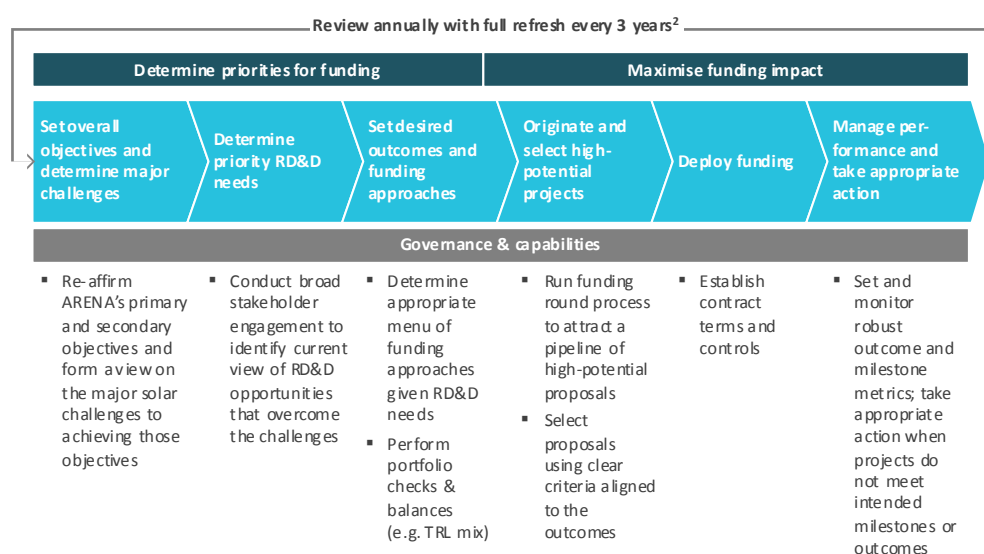
The review also identified opportunities for ARENA to continue to improve its model. ARENA's approach to investing has been iterative and there are opportunities to now formally confirm the practices shown to have most effect and to learn from best practice globally. Further, uncertainty surrounding ARENA's future and funding has significantly constrained ARENA's ability to undertake long-term strategic planning to set investment priorities and to commit to permanent design features in its operating model which support these priorities. In September 2016, the Australian Parliament passed legislation concerning the future funding profile of ARENA. As a consequence, the agency now has \$800 million in available grant funding to support innovative energy technology until 2022. Importantly, it means certainty for ARENA and the renewable energy sector.

ARENA is working through its revised investment priorities following this development, making it an opportune time to assess how ARENA can ensure it institutionalises the best features of its current approach and operating model, and make a set of longer term strategic choices about future priorities and operating model optimisation.

ARENA's investment process – validated by comparison with global models – broadly has six core steps (see Exhibit 14).

Six-step repeatable investment process

Proposed repeatable process for ARENA¹



¹ The detailed steps for performing each step of the repeatable process will be provided in a separate document.

² The three-year refresh involves resetting RD&D needs. Annual review involves refreshing RD&D needs and adding or refocusing projects as appropriate.

Step 1: Set overall objectives and identify major challenges to achieving them

ARENA has an annual process for setting strategic priorities for investment in renewable energy. Each year, ARENA produces a General Funding Strategy (GFS) and Investment Plan, which respectively establish the overarching strategic framework for program development and determine ARENA's investment priorities. These documents interpret and apply ARENA's primary legislated objectives to improve the competitiveness of renewable energy technologies and increase the supply of renewable energy in Australia.

The priorities articulated in the GFS and Investment Plan are high-level as they apply across ARENA's portfolio. Uncertainty about ARENA's funding has also meant that the documents have had to be sufficiently broad to accommodate a range of possible funding amounts and approaches. Interviews with ARENA staff suggested that this has meant that the plans do not always readily translate into specific guidance for priorities for designing solar RD&D projects. Further, in some instances the cycle for developing or approving plans has been out of sync with investment rounds, meaning that they are produced after or in parallel with investment rounds, rather than prior to their design, which is optimal.

This can be addressed by supplementing primary objectives in mandatory investment planning documents with secondary and more specific objectives or by preparing more specific investment guidance to accompany the GFS and Investment Plan.

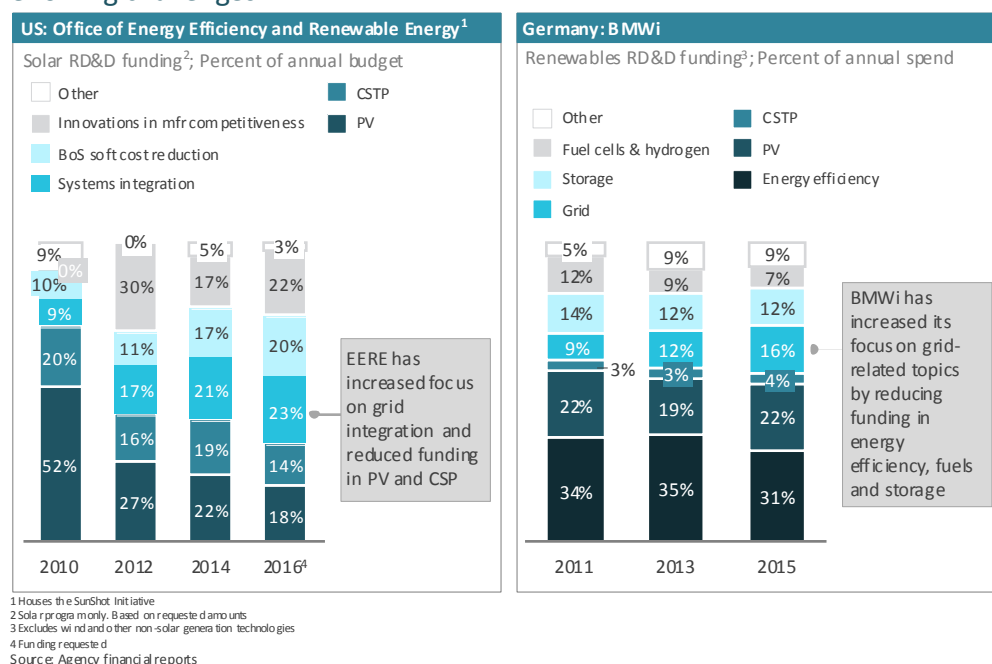
Step 2: Determine priority RD&D opportunities

Based on a synthesis of inputs from the research community and other experts, ARENA formulates broad research priorities for the funding rounds.

A comparison with global best practice shows that a more targeted approach to priority setting in advance of funding rounds- with strong engagement with stakeholders – is the more efficient approach. This view was also supported by ARENA staff interviews. The global analysis found that leading funding agencies’ approach to prioritisation is objectives-driven (that is, the agency identifies a particular challenge or target the research should meet, rather than investing in a technology area) and both primary and secondary objectives are clearly laid out. Priorities are focussed (but not restrictive) and are proactively updated to account for evolving market and technology conditions (refer to Exhibit 15).

Exhibit 15

International peers regularly update their priorities to reflect evolving challenges

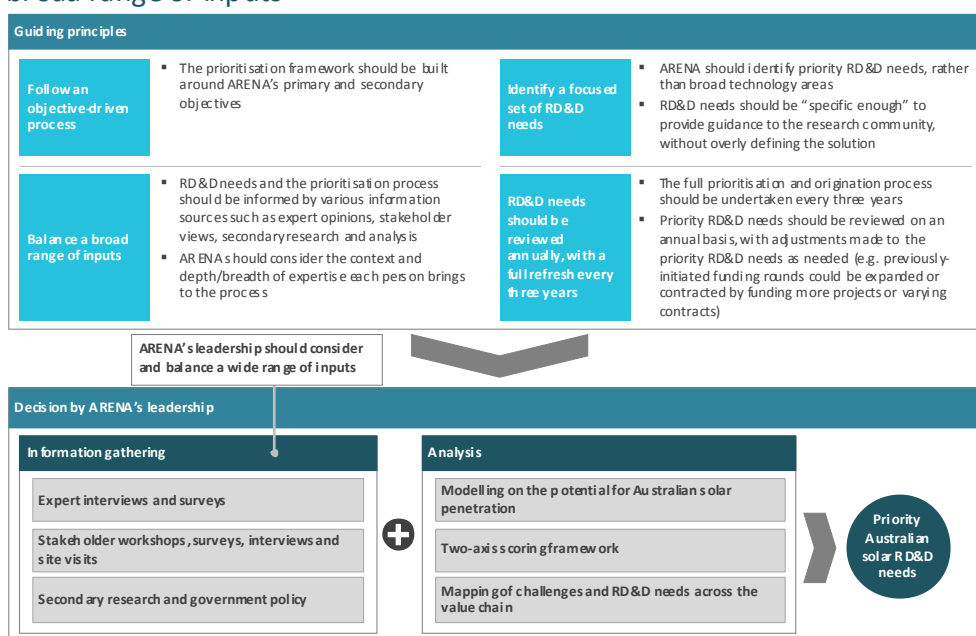


This allows for potential RD&D needs to be ranked according to ARENA’s objectives with a view to selecting the highest priority needs for Australian government investment. RD&D needs should be specific enough to provide guidance to the research community, without assuming the solution. The result of this process is a prioritisation of RD&D needs which collectively will deliver on the agency’s primary and secondary objectives. These high-priority research needs (illustrated in the upper-right of the framework in Exhibit 16) should be further validated by stakeholder engagement.

ARENA has instituted such a priority-setting process through a review of its overall investment framework and priorities, and deep-dive reviews into major technologies and programs within ARENA’s investment portfolio, of which this study is one.

A similar, full ‘clean sheet’ origination and prioritisation process should be repeated approximately every 3 - 5 years. Priorities should also be reviewed on an annual basis, with adjustments made as needed (e.g. previously-initiated funding rounds could be expanded or contracted by funding more projects or varying contracts).

ARENA’s leadership should select priority RD&D opportunities based on a broad range of inputs



Step 3: Set desired outcomes and investment approaches

ARENA has trialled multiple approaches to determining outcomes ahead of allocating funding via a funding round. For funding rounds under the RD&D program, and for the open call for applications under the ARP, ARENA has provided wide-ranging scope for applicants to nominate research and technology priorities. By comparison, ARENA’s approach to the large-scale solar round has been to specify priorities and then seek proposals that meet them through a competitive process. Feedback from staff interviews is that setting more specific outcomes has resulted in more effective outcomes for applicants and ARENA, by giving recipients clarity on the type of projects being sought, and making the assessment of projects more straightforward.

Once ARENA has identified RD&D outcomes for particular funding rounds, it designs the investment model (e.g. direct investment, industry co-investment, collaborative approach, research centre, or competitive round), financial instrument/s (e.g. grants, recoupable grants, and debt, equity and hybrid instruments) and contract length. In practice, >90 per cent of ARENA’s funding allocations for solar RD&D in FY16 have been via non-recoupable grants. This is partly due to the nature of projects being funded and partly due to ARENA’s enabling legislation, which limits ARENA to providing financial assistance and prevents ARENA from recouping more than the value of the money it has invested in a project. Efficiency of investment is also maintained through a requirement that projects demonstrate value for money – which may include matched funding or an industry partnership.

ARENA is currently working with other agencies on a legislative change that would provide it with more scope to utilise a broader range of instruments. ARENA is simultaneously undertaking work to identify the different forms of transactions it could utilise and the circumstances in which they’d be

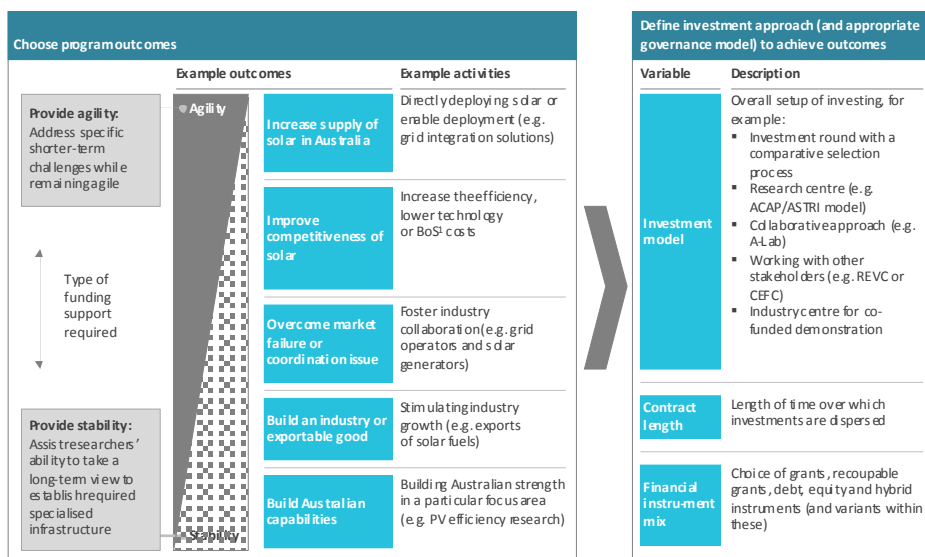
appropriate to deploy. This will increase ARENA’s ability to tailor the investment model to the outcomes it is trying to achieve in each RD&D need (refer to Exhibit 17).

In future, ARENA should consider how best to tailor its investment model to priority RD&D needs. This includes adopting models suited to both early stage and near commercial research. It also means adjusting funding to the timeframe for the work. If an RD&D need is relatively short term, an agile investment model such as direct performance-oriented grants may be appropriate.

Alternatively, where the RD&D need is more long term or complex, ARENA may wish to establish a research centre under a longer-term contract to achieve long-term stability in order to build Australian capabilities and build a long-term, collaborative approach amongst all the actors who have a stake in furthering a critical field of research. Grid integration, for example, could be a candidate area for a future institutional research model as it will be a significant, ongoing challenge for solar and other renewable energies that will require both multi-disciplinary research and a high degree of industry, researcher and regulator collaboration to solve.

Exhibit 17

Program outcomes should be defined before the investment approach is chosen



1 Balance of system

Step 4: Originate and select high-potential projects

ARENA has also utilised multiple approaches to project origination and selection. For competitive programs or funding rounds, ARENA will typically advise applicants of its priorities in advance of a round opening for applications, but then halt any active co-development of projects with recipients once the round opens to ensure a level playing field. For the ongoing, open application process under the ARP, ARENA may play a more active role in working with applicants during their application process to provide feedback on a proposal. Staff interviews for this study identified a set of practices that have proved most successful for ARENA, which were then validated against a comparative analysis with peer funding bodies globally. These practices were:

- **Proactive approach to project origination** – the quality of proposals is higher where ARENA proactively interacts with investment applicants to develop high-quality proposals before investment rounds open. This can include workshopping priorities and different funding instruments with applicants to ensure there is a high-quality pipeline of projects to invest in and applicants are aware of the best form of funding to suit each project’s TRL stage and needs and maximise a commercial return to ARENA where appropriate
- **Investment rounds focused on specific areas** – investment rounds where focus areas have been specified have resulted in a higher quality of proposals. This involves calling for activities that share a conceptual link (i.e. overcoming the same challenge) or are at a similar TRL stage.
- **Calibrated investment round amounts** – investment rounds have worked best where the level of investment is calibrated to likely demand to encourage competition between recipients and the highest-quality proposals, rather than setting aside a fixed proportion of funding for a broad area which may be underspent.
- **Deadline driven process** – Setting a deadline for proposals, rather than using rolling rounds, ensures all proposals are compared against each other so that only the best are funded.
- **Some investment held in reserve for ideas outside focus area** – ARENA could continue to allocate an adequate sum to proposals that are not constrained to priority themes, either via a collaborative institution such as ACAP and ASTRI, or via an open investment funding round. Guiding principles for selecting such projects could include the excellence of the research (for early stage research) and the likelihood of the research leading to commercial outcomes (for projects in the development and demonstration stages).

ARENA will need to ensure it has access to the right technical and investment-related expertise/capabilities matched to the funding models it is seeking to support. Building on its existing resources ARENA can further improve its access to expertise by:

- **Establishing a procurement panel for technical advice**, which can be added to on an ongoing basis.
- **Utilising two expert advisory panels** – one tailored to early stage research and one tailored to near commercial projects – more often and more broadly throughout the 6-step investment approach.

Step 5: Deploy investment

Once projects are selected, ARENA negotiates contractual terms with successful recipients. ARENA has built-up considerable, sophisticated expertise in its transactions team over the course of multiple funding rounds, and has applied these lessons to the ongoing improvement in the design of contracts and to its goals for achieving financial outcomes. This involves:

- **Clear milestones** – setting clear outcome and milestone metrics in collaboration with recipients (and leveraging expert input).
- **Clear financial outcomes where appropriate** – where the investment instrument involves an ongoing financial relationship (e.g. any instrument other than a non-recoupable grant), ARENA

needs to establish a simple and transparent mechanism for repayment. These mechanisms will vary based on the instrument across debt, equity and recoupable grants.

A consequence of ARENA inheriting projects from prior funding bodies – and improving its approach over time – is that the terms of projects in ARENA’s portfolio now vary. There would be value in ARENA undertaking a targeted review of its existing projects to identify projects which have multiple years to run and which would benefit from a variation/s to adopt more efficient or targeted terms.

Step 6: Manage performance and take appropriate action

ARENA has a dedicated and expert projects team which manages projects once a funding agreement is in place. The team’s work includes liaising with funding recipients, contract management and negotiation, and knowledge sharing. The team has made a series of improvements to project management, including improving data collection and transparency over impact metrics, such as patents, TRL improvement, publications and full-time equivalent RD&D staff supported.

The strategic review and Mid-Term Reviews of ACAP and ASTRI observed areas where ARENA could strengthen its evaluation and performance management of projects and minimise the administrative burden on applicants and ARENA. This includes:

- **Portfolio review and impact evaluation:** ARENA is developing evaluation frameworks and program logics for different portfolio elements and projects in some cases, with evaluations being progressively rolled-out. The data derived from this work could be integrated with an annual portfolio review and priority setting processes.
- **Milestone setting:** ARENA’s contract negotiation process could provide more room for milestones to be calibrated to a project’s characteristics such as size, TRL and risk profile. The latitude given to recipients in nominating milestones produces variations in quality and specificity – ARENA could improve the milestone setting process by aggregating lessons on best practice for milestone setting, to share with applicants and ARENA teams for future contract negotiations.
- **Performance management:** performance of projects is managed against contract milestones. In practice, fewer than 7 per cent of ARENA solar RD&D contracts were terminated in FY16, with contractual terms limiting the circumstances in which funding can be reduced or withdrawn, although around a third of contracts had a major variation made in FY16. For future contracts, ARENA could include more capacity in the contractual terms to review and change funding allocations based on both positive performance (e.g. more advances were made than originally envisaged), under-performance, or to reflect a significant shift in ARENA’s funding priorities.
- **Administrative improvements:** both applicants and ARENA staff have identified opportunities to streamline current approaches and lower the administrative burden, such as reducing the need for minor variations by providing more flexible wording in contracts (such as linking milestones to a time period rather than a specific date). ARENA could implement these changes by conducting a quick ‘impact and ease’ assessment of projects that would benefit from such a change, prioritising projects that will run into 2018 and beyond and which were negotiated under earlier programs with contractual provisions that do not reflect ARENA’s current best practice. This will ensure that the effort focuses on projects where the ROI of

doing the review and making a contractual variation is higher than simply letting the project run its current course.

5.4. Implementation of recommendations

Confirmation that ARENA will continue as an agency and receive new funding provides a good opportunity to consolidate the best of its existing investment practices into a repeatable ‘six-step’ investment approach and embed these practices across ARENA.

This study produced an implementation roadmap and three month implementation plan setting out how ARENA can execute the changes recommended in this report. These activities will need to be consolidated with other related activities underway at ARENA, such as the revision of ARENA’s Investment Plan. The activities ARENA should prioritise in the first three months of implementing the findings from this solar strategy refresh are:

- **Undertaking an annual whole-of portfolio stocktake of annual performance** – ARENA should collect and monitor data on milestone performance, and use this to populate a whole-of-portfolio performance tracker. Milestone performance data should be easily accessible and updated at each milestone stage-gate. Strategic alignment with ARENA’s objectives should be assessed annually by experts familiar with the technology.
- **Developing a response to the Mid-Term Reviews of the ACAP and ASTRI programs and implement them** – ARENA should work with the leaders of major programs to develop a response to the Mid-Term Reviews, including considering: appointing one or more external advisors to the program’s existing governance structures; creating more diverse and inclusive representation and skill sets at senior management levels, particularly with respect to commercial development capabilities; and minimising the administrative burden associated with the program, such as more streamlined reviews of the major programs.
- **Strengthening the approach to project management of ARENA’s portfolio** by instituting a more streamlined approach to performance management of contracts.
- **Confirming ARENA’s investment priorities for solar RD&D research and the funding approaches** that ARENA will utilise to realise them and integrating these with ARENA’s broader investment plans and priorities.
- **Consulting with stakeholders** on proposed investment priorities and strengthened and streamlined approach to investment.

ARENA should also take the opportunity to reduce the administrative burden of its investment activities. ARENA’s commercial orientation has created an innovative and agile culture and a generally lean approach to designing processes and core systems. However, both ARENA and funding recipients have identified areas where ARENA can further streamline its current practices to minimise the administrative burden associated with its investment process. This includes:

- A simpler and less onerous project investment application approach requiring less detail from applicants at the first, EOI stage;
- A more flexible approach to drafting milestones that is not linked to a specific date, unless critical, to limit the need for unnecessary variations; and,

- Differentiation of project performance management depth based on project size/risk and avoid the perception that exists amongst many researchers that they are being ‘micro-managed’.

The Mid-Term Reviews of the ASTRI and ACAP programs also recommended that ARENA and the two initiatives consider ways to assist ACAP and ASTRI to reduce their budget allocation to administration by identifying ways to lower ARENA’s administrative and compliance burden, and that ARENA consider adopting internal KPIs setting-out time limits within which ARENA decisions are made and implemented with respect to assessment of performance against milestones and requests for variation to its program (including milestones and KPIs).

These changes should be implemented by ARENA for its current portfolio of projects where the projects extend beyond 2018 and the administrative effort to amend contracts is less than the administrative benefit associated with ongoing variations, and to any future investments.

Investment approach recommendation: Confirmation that ARENA has a continuing role and will receive ongoing new investment funding makes it an opportune time for ARENA to confirm the best features of its current approach and operating model, and make a set of longer term strategic choices about its future priorities and operating model. This should include:

- Confirming ARENA’s role and core activities within the industry landscape.
- Strengthening investment practices in the ‘six-step’ investment approach; and
- Minimising the administrative burden on ARENA and funding recipients.

6. Appendix A – Expert Panel Members

An expert panel provided guidance to the solar RD&D strategy refresh



Dr Bruce Godfrey (Chair)

- CEO, Australian Scientific Instruments Pty Ltd
- Former Chair, ARENA Advisory Panel
- Relevant experience: solar PV commercialisation



Prof Christian Sattler

- Head, Solar Chemical Engineering, German Aerospace Centre (DLR)
- Relevant experience: solar chemistry and solar material conversion research



Jurgen Kern

- Research Associate, Systems Analysis and Technology Assessment, Institute of Engineering Thermodynamics, German Aerospace Centre (DLR)
- Relevant experience: solar deployment project management



Dr Peter Laver

- Senior Advisor, Australian Academy of Technological Sciences and Engineering
- Former member, CRC Committee and MRET Review Panel; former Chair Energy R&D Corporation
- Relevant experience: director and advisor for various research organisations (not solar specific) including VP Research and Development for BHP



Paula Mints

- Founder and Chief Market Research Analyst, SPV Market Research USA
- Relevant experience: PV solar technology and market analysis



Dr Will Howard

- Assistant Director, Office of the Chief Scientist
- Research scientist in oceanography, earth sciences and marine geosciences
- Relevant experience: government research advisor



Dr Charles Gay

- Board – Enki Technology
- Multiple Advisory Committees including - State Key Lab for PV, Trina Solar; Iris PV; Natcore Solar; BCleantech; Plant PV; USA
- Relevant experience: Advanced technical knowledge in PV solar technology