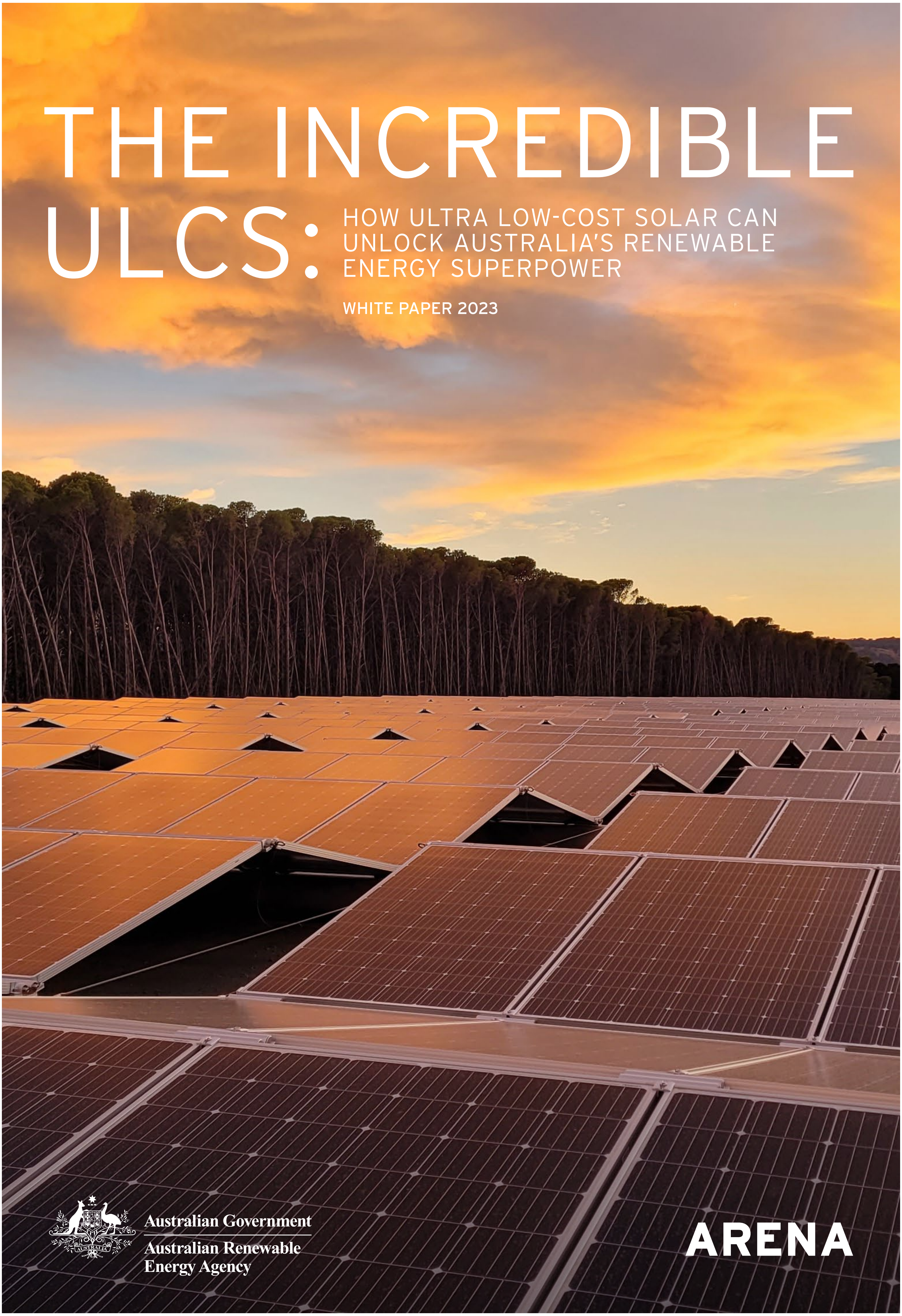
THE INCREDIBLE ULCS: HOW ULTRA LOW-COST SOLAR CAN UNLOCK AUSTRALIA'S RENEWABLE ENERGY SUPERPOWER

WHITE PAPER 2023



Australian Government
Australian Renewable Energy Agency

ARENA

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ACKNOWLEDGEMENT OF COUNTRY

ARENA acknowledges the traditional custodians of Country across Australia and their continuing connection to land, sea and community. We pay our respects to elders past and present.

Cover image: Happy Valley, 5B

OBJECTIVES AND SCOPE OF THIS PAPER

The main objectives of this paper are to:

- **elevate solar photovoltaics (PV)** in Australia's national priorities by outlining the benefits that extremely cheap solar could unlock, and
- **communicate key barriers and innovation priorities** for ultra low-cost solar to government, industry and the Australian public.

A set of **coordinated activities is required** to ensure that Australia can successfully deploy the scale of solar PV needed, not just to realise the Government's target of 82 per cent renewables in our electricity system by 2030, but to reduce the cost of solar PV even further beyond 2030 and realise the vision of Australia as a renewable energy superpower. These activities include ensuring that Australia has a vibrant local solar PV industry, there is offtake certainty for new solar developments, there is adequate deployment of energy storage, and new transmission lines are built out.

This document is intended to start the conversation. ARENA will continue to play a major role by investing in research and development and supporting the commercialisation of new technologies. We are also supporting the Solar Supply Chain Roadmap with the Australian Photovoltaic Institute (APVI), which aims to clarify where Australia should focus its efforts for developing local industry.

While this paper briefly touches on the challenges for near-term deployment of solar to decarbonise our electricity system, it is primarily focused on the role of **extremely cheap solar beyond 2030 to achieve Australia's ambition to become a renewable energy superpower.**

This paper primarily focuses on the **utility-scale market**, comprised of systems connected to the electricity grid ranging in size from hundreds of kilowatts to thousands of megawatts of solar power.[i] We also acknowledge there is an important role for behind-the-meter solar PV for residential, commercial and industrial users, as well as smaller-scale solar PV connected to the distribution networks. Innovations that drive down the cost of utility-scale solar can also benefit these markets.

EXECUTIVE SUMMARY

Urgent action must be taken to accelerate Australia's progress towards 43 per cent emissions reduction by 2030 and net zero emissions by 2050. Solar photovoltaics (PV) will be one of the most important technologies to achieve decarbonisation of the global energy system, however, a step change in costs is needed to unlock its full potential.

Australia has long been at the forefront of solar PV innovation, from research and development in our universities through to startups reimagining how solar farms can be designed and deployed. Homegrown innovations and increasing scale have cut the cost of solar PV by 85 per cent over the past ten years and it now contributes around 15 per cent of Australia's total electricity generation. Today's solar PV technology is already **mature and sufficiently cost effective to deploy at scale.** It requires no significant technology breakthroughs to achieve Australia's 2030 goals within the electricity system provided we can make strides with critical enablers such as energy storage, flexible demand, transmission and grid connection.

However, **ultra low-cost solar** could lead to much cheaper electricity for Australians and export opportunities to neighbouring countries, as well as supporting the decarbonisation of hard-to-abate sectors such as industry and transport. Ultra low-cost solar has the potential to provide the cheap primary energy we need to displace fossil fuels through the electrification of industrial processes, the production of green hydrogen and synthetic fuels, and ultimately to power direct air capture to remove excess carbon dioxide from the atmosphere and offset any remaining emissions in these sectors. By significantly reducing the cost of renewable electricity for manufacturing processes and enabling the production of green hydrogen below $2 per kilogram, **Australia could become a renewable energy superpower.**

ARENA has a 30-30-30 vision for ultra low-cost solar in Australia. This represents **30** per cent solar module efficiency and an installed cost of **30** cents per watt by 20**30**. This vision requires a step change from where we are today at around 22-23 per cent solar module efficiency and over $1 per watt installed cost. In terms of total levelised cost of energy (LCOE), our vision requires a drop to around one-third of today's solar LCOE to below $20 per megawatt hour.

Ultra low-cost solar is distinguished from today's solar technology by being much more **efficient** at converting sunlight to energy. It is manufactured at low cost from **affordable, abundant, safe and stable materials,** then deployed in a highly **efficient, automated** way in the field. Ultra low-cost solar is **reliable,** requires little ongoing maintenance, and may have a longer lifetime than today's solar PV technology. It is **low risk** and able to be financed at low rates by the world's largest financial institutions.

As a cutting-edge new technology, ultra low-cost solar must tick all these boxes as the characteristics are fundamental to it being a scalable and bankable product. Ultra low-cost solar is poised to become the **backbone of our future energy system**, beating fossil fuels on price and performance as well as accelerating our successful transition to a new renewable energy system.

While it will not be easy to achieve ultra low-cost solar, the goal is within reach. Innovation is needed to realise significant cost reductions including much higher efficiencies in converting sunlight to usable energy, a reduction in material costs, novel approaches to designing and deploying the technology in the field, and improvements in how solar farms are operated and maintained.

There are also non-technology enablers that must be activated. These include scaling up local supply chains, improving end-of-life management for solar panels, closely engaging with communities and traditional landowners, scaling the workforce to deliver the projects, rapidly expanding and connecting our grid infrastructure to these new assets, and ensuring there is offtake certainty for utility-scale solar PV projects.

Australia's governments, market bodies, developers, investors and innovators must commit to the task of dramatically driving down the cost of solar PV. Reaching this ambitious goal will require significant technological and commercial innovation, as well as collaborative effort to develop local industry and accelerate the deployment of projects.

ARENA will continue to play a major role by investing in research and development and supporting the commercialisation of new technologies to achieve our 30-30-30 vision. We are also supporting the Solar Supply Chain Roadmap with the Australian Photovoltaic Institute, which aims to provide more clarity on where Australia should focus its efforts and develop a set of recommendations for next steps. **In parallel, a step up in activity from other stakeholders across government and the private sector is critical to realising this opportunity.**

184 YEARS OF SOLAR INNOVATION

Climate change is here and the door is closing for the globe to stay within 1.5°C warming *(see callout box)* to avoid potentially disastrous climate tipping points. Urgent action must be taken to accelerate our progress towards net zero, with solar featuring as one of the heroes in this story. Along with wind generation, solar is one of the most important technologies to decarbonise the global energy system. This is especially the case in Australia where we have limited hydroelectric resources compared to many other countries, as well as limited prospects for the deployment of nuclear energy before 2030 due to state and territory bans and significantly higher costs than wind and solar energy.[ii] Solar is essential to reducing emissions across electricity, industry, transport and buildings, as well as powering negative emissions technologies such as direct air capture (but more on this later).

WHY IS 1.5°C IMPORTANT?

The Paris Agreement, negotiated by 196 parties at the 2015 United Nations Climate Change Conference, set a goal to hold global average temperature increases to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C. According to the latest Intergovernmental Panel on Climate Change (IPCC) Synthesis Report:

"Climate change is a threat to human wellbeing and planetary health. There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all... The higher the magnitude and the longer the duration of overshoot [of 1.5°C], the more ecosystems and societies are exposed to greater and more widespread changes in climatic impact-drivers, increasing risks for many natural and human systems... Overshooting 1.5°C will result in irreversible adverse impacts on certain ecosystems with low resilience, such as polar, mountain, and coastal ecosystems, impacted by ice-sheet, glacier melt, or by accelerating and higher committed sea level rise." [iii]

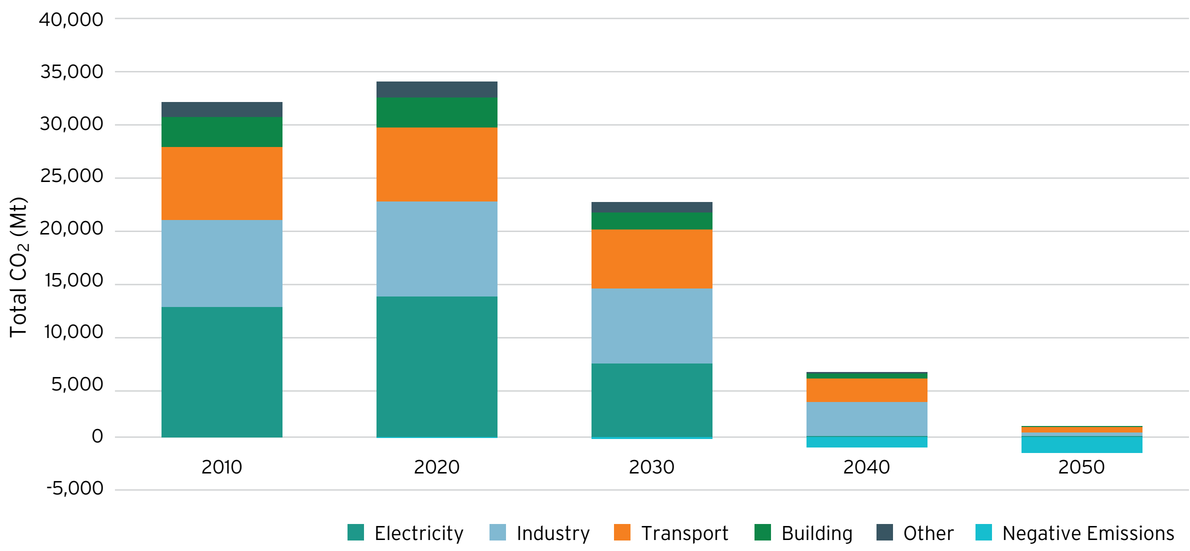


Figure 1 – Global CO_2 emissions in the Net Zero Emissions by 2050 Scenario (International Energy Agency)[iv]

The amount of solar energy that reaches the Earth's surface in one hour is enough to supply the world's current energy needs for more than a year.[1] As solar PV has few moving parts and requires no ongoing fuel inputs, it has extremely low operating costs. Once installed, it generates low-cost zero emissions energy for up to 30 years,[2] making it one of the cheapest forms of energy generation in history.

Utility-scale solar PV can be used for:

- domestic electricity use, which will grow with increasing electrification of industry, homes, businesses and transport,
- international electricity demand, through the direct export of electricity to neighbouring countries such as Singapore and Indonesia, and
- the production of hydrogen and other fuels for domestic and/or export purposes, and to provide the energy needed to upgrade our minerals into higher value zero emissions products for export.

There is a range of forecasts for the future scale of solar PV in Australia. The Australian Energy Market Operator (AEMO)'s Integrated System Plan (ISP), currently our best planning document, sets out the infrastructure required for the energy transition to play out while maintaining a secure and reliable supply of electricity. The ISP forecasts 70 gigawatts (GW) of utility-scale solar PV and 69 GW of distributed solar PV by 2050 to meet domestic electricity demand under its Step Change scenario.[v] The Net Zero Australia project found that Australia needs about 40 times the total generation capacity of today's national electricity market to achieve net zero by 2050, including 1.9 terawatts (TW) of solar PV capacity.[vi]

Renewable electricity and fuel exports could replace the energy currently exported by Australia through liquified natural gas (LNG) and coal. In this paper, as one scenario, we consider the replacement of Australia's LNG exports with green hydrogen produced with solar PV having achieved the 30-30-30 vision.[3]

Australia is a world leader in the production and export of fossil fuels. In recent years, our nation has become one of the world's largest producers of LNG, a high value commodity desired by economies including Japan, China and South Korea. In 2022, Australia produced more than 80 million tonnes of LNG, and was the world's second largest exporter.[vii]
To produce green hydrogen with an equivalent energy content, we would need to install 1-1.4 TW of solar PV depending on system design,[4] which is more than 100 times higher than Australia's current utility-scale solar capacity.[5] Assuming technology and construction advances by 2030, this amount of solar PV could require 7,000-11,000 km^2 of land.[6] While this may seem significant, it represents around 0.1-0.15 per cent of Australia's land area, and pales in comparison to land use in other sectors.[viii] For example, agriculture currently uses approximately 4.3 million km^2 of Australia's land, which is 55 per cent of our total landmass and between 400 to 600 times the area that would be required for solar PV in this scenario.[ix]

1 'Energy needs' means current global energy requirements from all fuel sources across all sectors.

2 Plants are guaranteed to operate for at least 25 or 30 years with a maximum degradation of about 12.5 per cent, however, many would typically operate for more than 40 years and can be repaired and upgraded for longer operational lifetimes.

3 This is not a forecast of future requirements for solar PV but a proxy that can be used to understand the land and manufacturing requirements of a significant scale of generation.

4 High-level estimate based on 4600 PJ of LNG being equivalent to ~32 Mt Hydrogen, daytime electrolyser operation, 55kWh/kg electrolyser yield, best in class solar technology with high performance bifacial cells. Two system designs considered: 1) Single Axis Tracking and 2) East-West array.

5 Based on CER accredited utility scale solar power stations as at 31/03/2023.

6 Estimated land use based on 545W, 2.6m^2 utility size panels scaled to 30 per cent module efficiency (estimate for 2030) and optimised system layouts to achieve maximum ground coverage ratios for the two design scenarios.

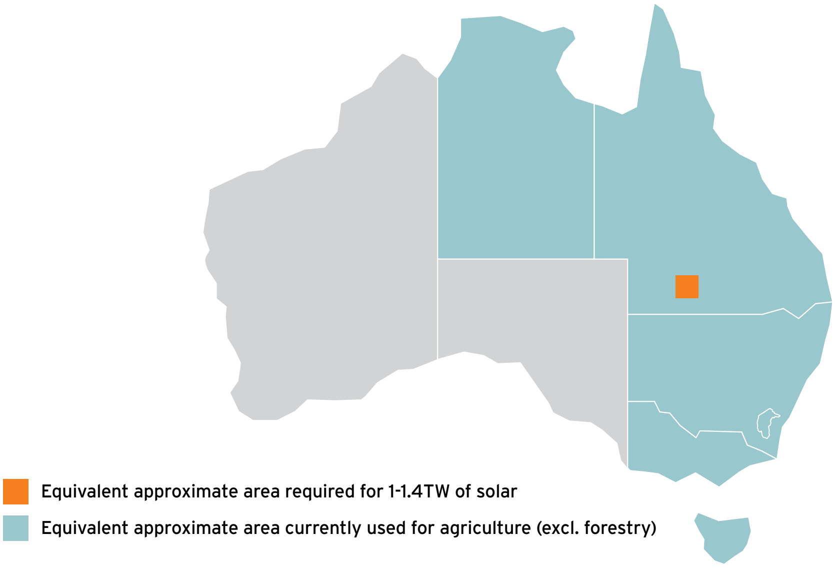


Figure 2 - Illustrative comparison of equivalent land required for agricultural land use and area required for 1-1.4TW of solar PV (depending on PV system design and noting that this does not represent the actual location of the land used)

THE HISTORY OF SOLAR PV

The photovoltaic effect is a process where layers of semiconductors are exposed to sunlight, and the energy from the light hitting these materials knocks electrons free to generate an electric current. The most common semiconductor used for solar PV is silicon due to its abundance, efficiency and low cost.

The photovoltaic effect was first noted by French physicist Edmond Becquerel in 1839 and the first solar cells created by Charles Fritts in New York in 1883.[x] These early solar cells were less than one per cent efficient, and it took until 1954 to achieve efficiencies of more than five per cent.[xi] Early solar PV cells were used in applications where other power sources were highly impractical, such as in the space industry, where chemical batteries had a very short life. These cells were first used as a solution aboard the Vanguard satellite in 1958.[xii]

The US energy crisis in the 1970s led to the US government doubling down on solar. Research agencies were established and financial incentives were offered for residential uptake. In the 1990s Germany launched the 1000 Roofs Program, which was followed in the early 2000s by a feed-in tariff where solar electricity fed into the grid attracted a guaranteed rate for the next 20 years. This policy spurred mass manufacturing of solar modules (particularly in China) that led to rapid reductions in cost. By 2010 solar cost less than two per cent of what it did in the 1970s.[xiii] These huge cost reductions and the growing need for renewable energy led to solar PV cementing itself as one of the most important and fastest growing energy technologies in the world.

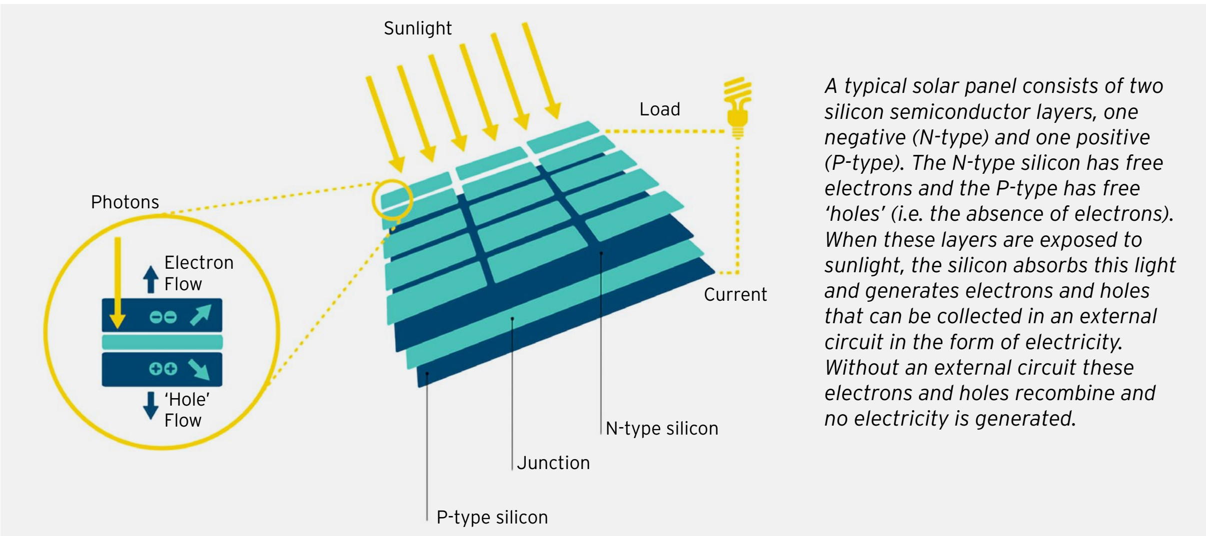


Figure 3 – Components of a solar cell and the photovoltaic effect (image: Good Energy)

AUSTRALIA'S ROLE IN SOLAR PV INNOVATION

Australia has long been at the forefront of solar PV research. Pioneer solar researcher Professor Martin Green and members of his team at UNSW, notably Professor Andrew Blakers, Dr Aihua Wang, Professor Stuart Wenham and Dr Jianhua Zhao, developed PERC solar cell technology *(see callout box)* in the 1980s and 1990s. This is currently the dominant solar technology globally and remains among the most efficient and commercially viable technologies. The development of a dedicated School for Photovoltaics and Renewable Energy (SPREE) and the Australian Centre for Advanced Photovoltaics (ACAP) at UNSW has also been a catalyst to produce world-leading solar research and successful entrepreneurs. An example success story is that of Dr Zhengrong Shi, a graduate of SPREE who founded Suntech Power in China, which became the world's largest manufacturer of solar panels in 2010.

SunDrive is an Australian solar energy company that is innovating on multiple fronts. Solar technology currently consumes 14 per cent of the world's annual silver, up from 5 per cent in 2014.[xiv] SunDrive has developed a solar cell that is not only free of silver but also highly efficient, setting a world record for cell efficiency in 2021. SunDrive has since improved upon that record with an efficiency of 26.41 per cent in 2022.

The way solar farms are designed and deployed has also come a long way, driven in part by Australian innovation. We started with fixed tracking systems before moving to single axis tracking (SAT), a technology that follows the sun over the course of the day and has led to large increases in energy production. By 2016, more than 90 per cent of new solar farms in Australia were using SAT. Now one of the most innovative ways to install solar farms is high-density fixed systems such as those developed by 5B. 5B is a homegrown startup improving the way solar farms are designed and deployed through a combination of pre-fabrication and automation in the factory and in the field.

With these innovations and larger-scale deployment over the past 10 years, the cost of utility-scale solar in Australia has dropped by more than 85 per cent, cell efficiency has increased by approximately four percentage points (an improvement of around 20 per cent) and the LCOE *(see callout box)* has dropped to less than half that of fossil fuels, reaching approximately $50/MWh in Australia.[xv]

CELL AND MODULE EFFICIENCY

Cell efficiency is a measure commonly used to compare performance of one solar cell to another. It refers to the portion of the available energy from sunlight that can be converted into electricity through the solar cell. The 'Shockley-Queisser limit', calculated in 1961, suggested efficiency was limited to 29-33 per cent depending on the semiconductor used in the cell. The most common solar cell material, silicon, is limited to around 29 per cent efficiency using a single-junction cell or one type of semiconductor. Researchers have spent decades improving the efficiency of these cells to reach this limit, as well as trying to surpass it by stacking multiple semiconductors to capture a larger fraction of the incoming solar spectrum, and by using alternative materials.

Module efficiency relates to the full solar panel, which experiences a lower efficiency due to losses such as wire/connection resistance and absorbance/reflection from glass module coverings.

WHAT IS PERC SOLAR CELL TECHNOLOGY?

PERC stands for Passivated Emitter and Rear Cell. This is an advanced solar cell design that includes additional layers to reduce electron/hole recombination and improve light absorption within the cell, thereby improving overall efficiency. This is achieved by removing recombination points (e.g. defects) within the surface layers of the cell, and adding an extra rear layer to reflect light back through the cell for a second chance at absorption.

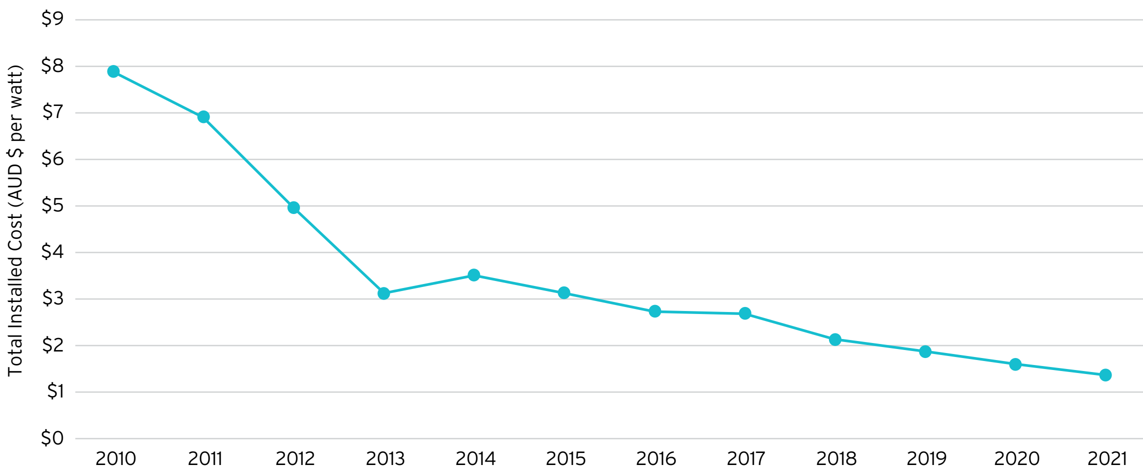


Figure 4 – Utility-scale Solar PV total installed cost trend in Australia from 2010 to 2021 (International Renewable Energy Agency) [xvi]

Solar now provides almost 15 per cent of Australia's electricity,[xvii] with approximately 10 GW of large-scale solar and 19 GW of rooftop solar installed.[xviii] The technology covers one third of our rooftops, making Australia the biggest user of rooftop solar in the world.[xix] We currently have approximately 100 GW of utility-scale solar in the development pipeline,[xx] however, a significant step up in capacity is needed for Australia to reach net zero.

WHAT IS LCOE?

The levelised cost of electricity (LCOE) provides a basis for comparing different generating technologies on a cost per unit of electricity. It incorporates the total cost of building and operating the generation asset per unit of total electricity generated over the asset's lifetime.

AUSTRALIA HAS A CLEAR ADVANTAGE IN ULTRA LOW-COST SOLAR

Australia has committed to reduce net emissions by 43 per cent by 2030 (compared to 2005 levels) and achieve net zero emissions by 2050. Modelling undertaken by AEMO for the ISP's Step Change scenario projected that renewables – solar, wind, hydro and bioenergy – supported by storage will make up 83 per cent of generation in Australia's National Electricity Market (NEM) by 2030-31 compared with 28 per cent in 2020-21.[xxi] The switch from coal-fired electricity generation to clean energy using solar PV and wind generation, backed up by energy storage and gas-fired generation, is core to the 2030 decarbonisation story.

According to the ISP, renewables supported by storage can provide more than 95 per cent of Australia's electricity needs by 2040.[xxii] This is due to our world-leading renewable energy resources and the geographic diversity that Australia's land mass offers. Today's solar PV and wind technologies are already mature and sufficiently cost effective to deploy at scale. No significant technology breakthroughs are required in solar PV to achieve this medium-term goal, provided we can make strides in the critical enablers such as energy storage, flexible demand, transmission and grid connection.

In Australia's case, solar energy has the potential to be the lowest-cost source of energy by a significant margin. Wind energy will play a crucial role in complementing the generation profile of solar but the levelised cost of wind energy is expected to only gradually reduce as technology improvements and learning rates are partially offset by moving to less favourable wind resource sites.

In contrast, solar PV in Australia has the benefit of untapped technology potential and fewer siting constraints. The chart below shows that solar learning rates have led to a continuous decline in installed cost, which is predicted to continue as total deployed capacity grows.

It might be tempting to declare victory and simply get on with the job of installing the technology that is available today. While we absolutely do need to continue installing today's solar technology on our rooftops and land, Australia must also pursue an ambitious step change in costs to enable the faster, lower-cost and more extensive transition needed beyond the next decade.

Ultra low-cost solar can unlock this technology's potential to be deployed at even greater scale than many currently imagine - perhaps over 1 TW of installed capacity in Australia by 2050. At that magnitude, solar could be our planet's most important technology, not just in our *electricity* systems but throughout our whole *energy* system, for example through the production of hydrogen, synthetic fuels and green energy products.

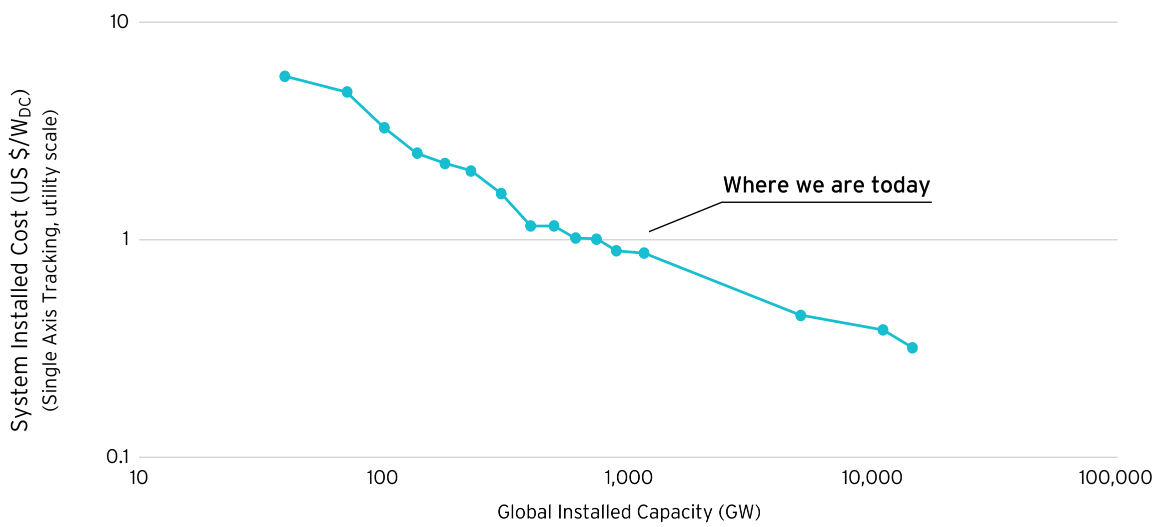


Figure 5 - Solar learning cost curve comparing installed cost to global installed capacity[xxiii]

ULTRA LOW-COST SOLAR WILL BENEFIT ALL AUSTRALIANS

Multiple benefits will arise from further efficiencies and breakthroughs in the ways solar PV is designed, manufactured and deployed in Australia's electricity system.

Improved module efficiencies and balance of plant design can lower land and material requirements for the same energy yield. More effective deployment can drastically reduce the time to get new solar farms built and operating. As a manufactured and modular product, cost savings and innovations early in the solar cell supply chain can have a flow-on effect throughout downstream activities. New inventions and new skills can get adopted quickly and have a ratcheting down effect on the cost of future products. Such innovation is essential to lock in cheaper and better ways of operating. Any cost savings, big or small, ultimately lead to lower electricity prices and lower priced manufactured goods for consumers.

Looking to the broader energy system beyond electricity, the path to net zero emissions is significantly more challenging and costly. This is particularly the case for hard-to-abate sectors across heavy industry and transport. Decarbonisation of alumina refining, steel making, cement and chemical production, shipping and aviation all require significant capital expenditure and technologies to be developed or matured. There are also many financial and social challenges to be solved.

However, at the core of this challenge is the need to generate very cheap energy that can be integrated into refurbished or new industrial operations. Solar has the potential to provide the cheap primary energy we need to displace fossil fuels through the electrification of industrial processes. This cheap energy can also be used to produce green hydrogen and synthetic fuels, and ultimately to power direct air capture to remove excess carbon dioxide from the atmosphere and offset any remaining emissions in these sectors.

This use of ultra low-cost solar offers a significant opportunity for Australia to be a leading low-emissions producer. Energy is a significant input into many manufactured products, with steel and aluminium having energy costs contributing as much as 17 per cent[xxiv] and between 30 and 40 per cent[xxv] of input costs respectively. Fuel production is a similar story, with energy costs making up approximately 42 per cent of input costs for hydrogen.[xxvi] Countries that produce cheap renewable energy on a large scale will have a comparative advantage in making and selling refined materials and manufactured products and future fuels into domestic and international markets.

ENERGY VS. ELECTRICITY

Energy is a catchall term for the types of 'work' that may come in many forms such as heat (e.g. by burning a material), chemical (e.g. liquid and gaseous fuels used in cars, ships and aeroplanes) or electrical energy. Electrical energy or 'electricity' is a form of energy that involves the movement of electrons to power devices such as electric motors, lights or computers and other devices.

COMPARATIVE VS. COMPETITIVE ADVANTAGE

Comparative advantage is based on the inherent features of a nation (such as strong natural resources) that enable it to produce goods at a lower opportunity cost than others.

Competitive advantage is created through competencies or assets and can be copied by others, such as innovative manufacturing methods.

AUSTRALIA: THE LUCKY COUNTRY

Australia has several characteristics that put us in a very strong position to produce low-cost renewable energy. Our continent has some of the highest levels of solar insolation[7] in the world, the sixth largest land mass at 7.7 million km^2 and the third lowest population density.[8] We have an abundance of minerals that can be used with cheap solar energy to make products such as direct reduced iron, green aluminium, lithium metal, copper and other metals that are key to the energy transition. We are a modern developed economy and trusted trading partner, with the ability to attract significant amounts of foreign capital if the investment conditions are right.

Growing recognition of these sources of comparative advantage has led to the idea of Australia becoming a renewable energy superpower.[xxvii] However, becoming a superpower brings with it the challenge and responsibility to decarbonise Australia's electricity grid, minerals value chains and manufacturing sectors. This can only be achieved with significantly lower costs than other markets in the production of renewable energy and its use in industrial processes.

Australia also has comparative disadvantages. We are a long way from our trading partners and as a developed country we have a high cost of labour relative to many developing countries. However, we can overcome these disadvantages if we produce electricity and energy at sufficiently low costs and sufficiently large scale.

7 Solar insolation is the amount of solar radiation that reaches a surface over a specified time and is generally expressed in W/m^2 or kWh/m^2 per day.

8 Including countries with a population over 100,000.

Australia can be a leader in the export of renewable electricity and green hydrogen, and the production of green materials and products for domestic and export use, while providing relief to the businesses and communities struggling with high electricity bills due to our current reliance on expensive coal and gas.

WHAT IF AUSTRALIA DOES NOT DO THIS?

If we do not make ultra low-cost solar a reality, we would be missing a huge economic opportunity and risking a slower and more difficult path to net zero.

Driven by our rich natural resources, Australia's economy today is largely dependent on commodity exports and services; our top six earners of foreign income are iron ore, coal, natural gas, education, tourism and gold. Notably, the top three are largely dependent on fossil fuels.

Australia is currently ranked 91 of 133 economies in the Atlas of Economic Complexity,[9] the Harvard University index on industrial capabilities and future growth prospects. We are clustered with developing countries on this list, and the nearest developed country in the rankings is New Zealand at 53.[xxviii]

This ranking and the nature of our current income highlight that Australia is exposed to numerous risks, including: long-term demand for fossil fuels is expected to decline, commodity pricing is highly volatile compared to that of manufactured goods (leading to less stable economic contributions), and commodities have been a declining sector of world trade since the nineteenth century.[xxix] If other countries secure the comparative advantage in high-growth products and industries, Australian manufacturing will likely decline further and we will ultimately become an even more service-based economy.

The slower our energy transition, the greater will be the challenge to reach net zero by 2050. If we do not act now to innovate and deploy this essential technology, the decade beyond 2030 will be significantly more difficult for us as a nation. The cheaper Australian solar PV becomes relative to other forms of generation, the greater comparative advantage Australia stands to gain in green electricity, fuels and products relative to most other countries, and the smoother our path to net zero.

9 This measure was last updated in 2020. The Economic Complexity Index is a metric used to quantify the productive capabilities of countries and has been shown to be correlated with important economic indicators such as income per capita and economic growth. This is one metric, and it should be noted that there are other measures used to understand the economic health of a nation (e.g. GDP).

RAPID TECHNOLOGICAL INNOVATION IS NEEDED TO REALISE THE VISION

ARENA has a vision to unlock the potential of ultra low-cost solar. We define ultra low-cost solar as electricity generated from solar PV at or below $20 per megawatt hour (MWh), around one-third of today's solar on a levelised cost of energy (LCOE) basis.

Ultra low-cost solar is distinguished from today's solar technology by being much more efficient at converting sunlight to energy. It is manufactured at low cost from affordable, abundant, safe and stable materials, then deployed in a highly efficient, automated way in the field. Ultra low-cost solar is reliable, requires little ongoing maintenance, and may have a longer lifetime than today's solar PV technology. It is low risk and able to be financed at low rates by the world's largest financial institutions.

As a cutting-edge new technology, ultra low-cost solar must tick all these boxes as these characteristics are fundamental to it being a scalable and bankable product. If this vision is realised, ultra low-cost solar would become the backbone of our future energy system, beating fossil fuels on price and performance as well as accelerating our successful transition to a renewable energy system.

To put ARENA's vision into perspective, this would mean moving from an average cost of around $50-60 per megawatt hour (MWh) today,[10] to below $20/MWh by 2030. Analysis from Aurecon commissioned by ARENA in 2021[xxx] suggested that the path to achieving this LCOE would require multiple major leaps in different aspects of PV technology performance, significant module cost reductions and favourable discount rates. This therefore represents a highly ambitious case of what could be achievable.[11]

The key cost levers are module efficiency, module price, and operations and maintenance (O&M) costs, which collectively account for up to 90 per cent of potential cost reductions in a typical single-axis tracking system.

PV module efficiency: Efficiency gains in PV technology are occurring incrementally for existing technologies, with silicon cell technologies increasing in efficiency by around 0.5 percentage points per year over the past ten years.[xxxi] Efficiency leaps are expected through a move towards n-type, heterojunction, and perovskite tandem PV technologies, the last of which could approach efficiencies of close to 40 per cent. This could contribute up to approximately 25 per cent of future LCOE reductions.

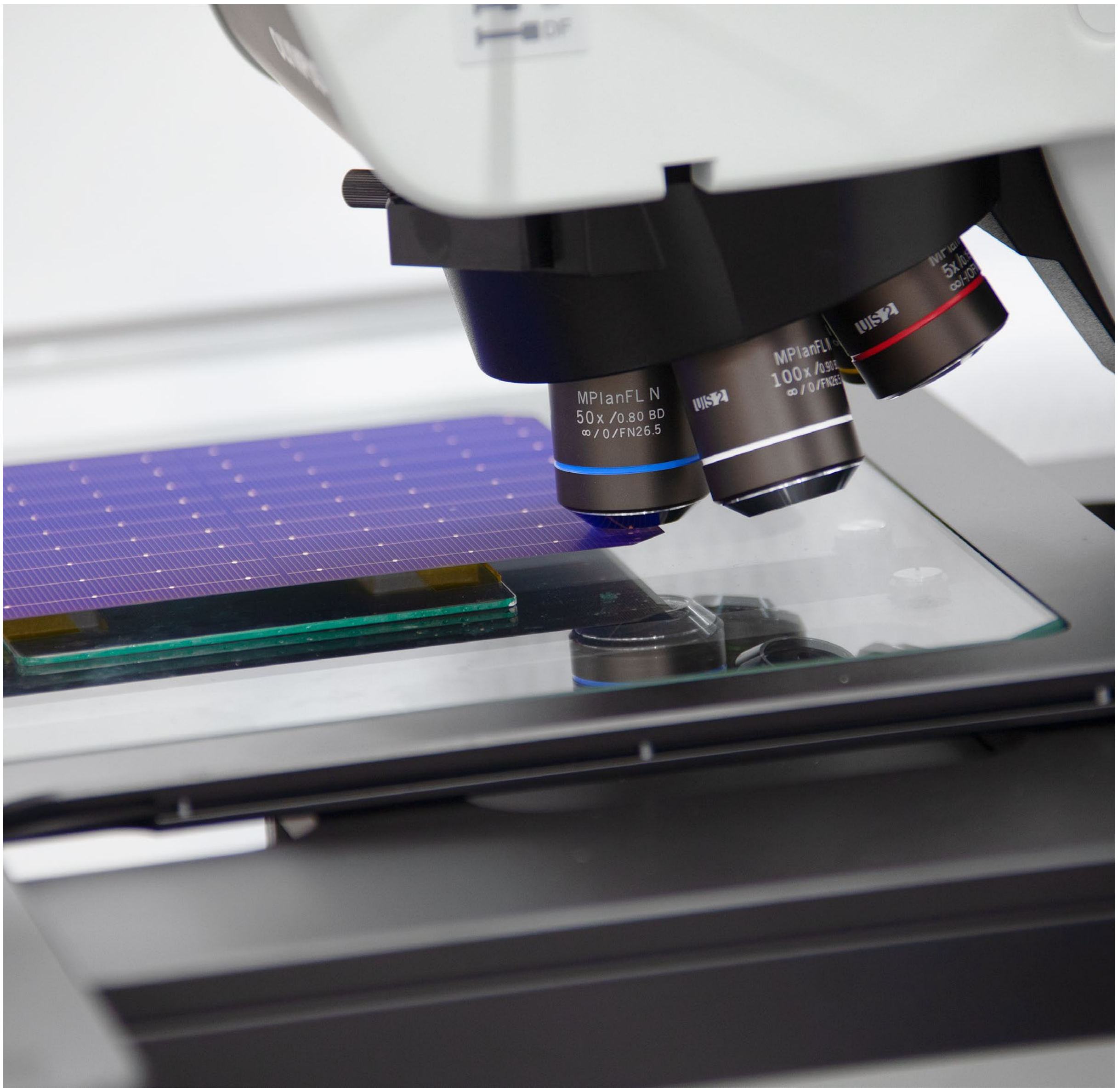
PV module price: Module price is another major cost lever for LCOE, and improved manufacturing methods such as the replacement of silver contacts with copper could have a significant impact.[xxxii] The International Technology Roadmap for Photovoltaics predicts that module prices could fall by 40-50 per cent by 2030, which could contribute up to approximately 25 per cent of future LCOE reductions.

Reductions in O&M costs: At current efficiencies, a 500 MW solar farm has around 1,300,000 PV modules to monitor and maintain. Modules can also become soiled, which may cause significant energy production losses. Most improvements are likely to be achieved through the emergence of specialised contractors who can efficiently provide O&M services to multiple solar farms, although there may also be a role for automated maintenance technology (e.g. cleaning robots to boost energy production) or intelligent monitoring systems. This could contribute up to approximately 20 per cent of future LCOE reductions.

Discount rates: Since the LCOE of solar is mainly related to the upfront costs of building the solar farm, the cost of capital can have a significant impact on LCOE. For example, reducing the discount rate from six to four per cent could reduce LCOE by around 20 per cent. In practice, lower financing costs for any technology is related to the perception of risk as well as the prevailing long-term rate of interest in the economy. In the case of solar PV, the key influences on discount rates are market risk, construction and connection risk, and performance risk. ARENA can influence construction and connection risk factors by demonstrating and de-risking new technologies and construction methods.

10 Based on an LCOE of $47/MWh for a typical Australian solar farm with 500MW AC rating in 2021.

11 The analysis was undertaken to understand the key cost levers required to reach below $20/ MWh, rather than to forecast a 2030 LCOE based on current data trends. A more realistic optimistic scenario gave an LCOE of ~$25/MWh by 2030. Analysis was also based on a limited survey size.



There is also an alternative to single-axis tracking systems that could be an important piece of the puzzle in achieving drastically lower LCOEs. Technologies that incorporate simplified designs, prefabricated systems and automation to significantly decrease the cost of deployment and balance of plant components.

Going below $20/MWh will not only require these significant step changes, but also hundreds of smaller improvements. Other innovations include:

- **Longer plant lifetimes and reduced degradation:** The lifetime energy production of solar PV plants is expected to increase through consistently lower degradation rates and increased project lifetimes. The typical solar PV project design lifetime may exceed 40 years by 2030.
- **Increasing bifacial gains:** The use of ground material or covers to increase albedo[12] is an unproven technology that has the potential to cause major boosts in bifacial yield. Bifacial performance (i.e. the bifaciality factor) is also likely to consistently improve.

However, the successful development and deployment of innovative solutions require more than just ground-breaking research. Clear commercialisation pathways are essential for translating core research into viable, market-ready solutions. Bridging these gaps will require ongoing collaboration and partnerships between researchers, startups and industry.

12 Bifacial solar panels produce solar power from both sides of the panel. Albedo is the fraction of light that a surface reflects, and it determines how much incoming solar energy is reflected towards space. If all light is reflected this value is 1.

CRITICAL NON-TECHNOLOGY ENABLERS ALSO NEED TO BE ADDRESSED

Australia will require a two-track approach to bring down the cost of solar: we must deploy at unprecedented levels to accelerate learning rates and realise economies of scale, and in parallel continue to innovate to improve cell efficiency and the way solar farms are designed and deployed.

There are also non-technology enablers to deployment that must be activated to reach the ambitious scale and cost reductions that are needed. These include scaling up local **supply chains,** improving **end-of-life management** for solar panels, closely **engaging with communities and traditional landowners,** scaling the workforce to deliver the projects, rapidly expanding and connecting our **grid infrastructure** to these new assets, and ensuring there is **offtake** certainty for utility-scale solar PV projects.

The next section discusses each of these in turn.

SUPPLY CHAIN SECURITY

Australia produces many of the raw materials used in solar PV projects but is currently reliant on imported manufactured and assembled products. We are particularly reliant on China, which currently manufactures more than 80 per cent of PV system components and an even higher share of other parts of the supply chain such as 98 per cent of silicon wafers. This lack in supply diversity creates a significant risk of price increases and project delays, which will only increase as global demand grows at unprecedented levels and we compete with other markets for these products.

Scaling up local supply chains could increase security for our domestic solar PV market, set up Australia for an export opportunity and enable the development of a green manufacturing industry using our cheap wind and solar.

A SIMPLE SOLAR PV SUPPLY CHAIN

The solar PV supply chain begins with the extraction of raw materials such as quartz, silver, copper, bauxite and iron ore. These are processed into refined materials such as polysilicon, silicon and steel. The next step is manufacturing and assembly of the various components of the system, such as solar cells, modules, inverters and trackers. Following this, the PV systems and electrical equipment must be installed in the field as efficiently as possible, and then there is ongoing maintenance for the 20-30 year life of the asset.

<table>
<tr><th colspan="3">MINING AND PROCESSING</th><th colspan="4">MANUFACTURING AND ASSEMBLY</th><th>O&M</th><th>RECYCLING</th></tr>
<tr><td>High purity quartz</td><td>Metallurgical silicon</td><td>Polysilicon</td><td>Ingots and wafers</td><td>Cells</td><td rowspan="5">Modules</td><td rowspan="6">System assembly</td><td rowspan="6">Several processes including: monitoring and fault detection, vegetation management, and component repairs and replacement.</td><td rowspan="6">Retrieving panels from site
End-of-life processing</td></tr>
<tr><td colspan="3">Aluminium, copper and silver</td><td colspan="2">Aluminium, silver and copper pastes</td></tr>
<tr><td colspan="3">Aluminium, steel</td><td colspan="2">Frames</td></tr>
<tr><td colspan="3">High purity quartz</td><td colspan="2">Glass</td></tr>
<tr><td colspan="3" rowspan="2">Copper, steel and aluminium</td><td colspan="2">Junction boxes, metallic ribbons</td></tr>
<tr><td colspan="3">Balance of plant (including power electronics, wiring and mounting)</td></tr>
</table>

Note: not exhaustive

Developing onshore capabilities and local supply chains is not necessarily about reducing costs. Local manufacturing may be more expensive than offshore manufacturing due to higher labour costs and lower economies of scale compared to countries such as China. However, it could create value by reducing supply risks and increasing economic opportunities for Australia. It could also reduce solar PV costs in areas such as transportation and logistics, which currently contribute around 15 per cent of total solar panel costs.[xxxiii]

Onshoring has become a more viable prospect for Australia as the cost of manufacturing has significantly reduced in recent years, driven by cheaper equipment and greater levels of automation. For example, the capex for 1 GW heterojunction solar equipment has reduced by approximately 70 per cent in the past four years.[xxxiv] While the development of manufacturing and assembly capabilities is still not a fast process, the manufacturing sector is being supported by federal and state governments through programs such as the National Reconstruction Fund.

To ensure we can meet our domestic solar PV needs and unlock a potential economic opportunity, ARENA is currently working on a Solar Supply Chain Roadmap with the Australian Photovoltaic Institute (APVI), which aims to provide more clarity on where Australia should focus its efforts and develop recommendations for next steps. The aim of the Roadmap is to re-establish solar PV manufacturing in Australia where it is economically viable, relevant in scale and timely, as well as providing Australia with a greater degree of control over the supply of solar PV technology.

To inform these recommendations, the Roadmap project will consider:

- current and projected local and international PV demand and manufacturing capacity
- technical, economic, business and policy options, opportunities and barriers
- opportunities to work with other trading partners such as India, the United States and other Asia-Pacific nations to diversify our PV supply chain.

In parallel, Australia will also need to consider how we can best partner with existing manufacturing leaders such as China, from research and development through to commercialisation.

END-OF-LIFE MANAGEMENT

Community concern about what happens to end-of-life solar PV panels is growing. In Australia alone, 100,000 tonnes of solar panels are expected to reach end-of-life each year by 2035. This is equivalent to around 1200 Boeing 737 aircraft. Put in context, however, Australia generates almost 70 million tonnes of waste each year, of which 1.4 million tonnes is glass packaging such as beer bottles and food containers.[xxxv]

Current rates of solar panel recycling are very low and most end up in landfill, which means wastage of valuable materials. Technical solutions are emerging but we need innovative solutions to improve ‘reverse logistics’, that is, the way we retrieve solar panels from use, and implement end-of-life processing. We also need the right policies and regulation to ensure critical infrastructure and incentives are in place.

SECURING SOCIAL LICENCE

There is a relatively high level of social acceptance for solar PV compared to most types of energy generation. However, securing social licence is likely to become more challenging with the exponential increase in the scale and number of solar PV farms across Australia. As the sector grows, effective and meaningful community engagement is critical. Companies must closely engage with communities on the local effects of their projects including economic and employment impacts, visual and environmental impacts, and the implications for electricity reliability and affordability.

We must also ensure that we treat traditional custodians with respect and inclusion. They are crucial partners and in many cases co-owners of the projects, with Indigenous land title now recognised in more than half of the Australian continent. Early and meaningful engagement with Indigenous communities is essential during development of solar PV projects. ARENA is working with organisations such as the First Nations Clean Energy Network to ensure that affected communities can take part in decision-making and share in the benefits of renewable projects.

THE RENEWABLE ENERGY WORKFORCE

To deliver on AEMO's ISP Step Change scenario, Australia will need an estimated additional 15,000 workers by 2025 and 40,000 workers by 2050. To make the Hydrogen Superpower scenario a reality, we will require an additional 35,000 workers by 2025 and an additional 195,000 workers by 2050. This includes workers to build and operate renewable generation and storage facilities as well as transmission lines but does not factor in the workers needed to mine raw materials, manage recycling, or deliver energy efficiency and electrification projects.[xxxvi]

Building this workforce will require the training and education of electricians, engineers, construction managers, and finance and business professionals. However, effort will be needed to attract qualified workers to these projects, given the strong competition for labour from other large infrastructure projects. This is especially challenging given the large proportion of skilled labour located in population centres, while most large renewable energy projects are in the regions. The Government's recently announced Net Zero Authority will help to transition this workforce.

Australia has built a world-leading mining industry with heavy reliance on automation. It is likely that a similar model will be required to make terawatt-scale solar a reality in Australia. If labour becomes the defining factor for installing solar, then Australia simply will not be able to compete with countries such as Saudi Arabia, Chile, Morocco and others who have much lower labour costs as well as abundant sunshine and land.

TRANSMISSION AND GRID CONNECTION

Today's electricity grid was not originally designed to connect the Australian locations where solar and wind farms are situated, or support two-way flows of electricity from distributed energy resources such as rooftop solar. According to AEMO's ISP, we need at least 10,000 km of new transmission lines in the eastern states alone to connect the nine times growth in solar and wind capacity to electricity users by 2050. While the Government is providing $20 billion in low-cost finance through the Rewiring the Nation plan, new transmission lines are not easy to deliver with projects taking up to seven years from the identification of a project through to completion.

Once the required transmission is in place, grid connection is one of the biggest challenges for large-scale renewable energy projects in Australia. Uncertainties around connection timelines, congestion and curtailment levels have already dampened investor confidence for new renewable projects across Australia.

There are various reforms underway by bodies including the Energy Advisory Panel, AEMO, Australian Energy Regulator and Australian Energy Market Commission to address these issues. Accelerating this work will be critical to avoiding further delays to the commissioning and connection of large-scale solar PV, and to avoid unnecessary curtailment of generation from these assets.

OFFTAKE CERTAINTY

One of the current challenges for near-term deployment of utility-scale solar PV is the competition with cheap rooftop solar PV, which has a very high level of adoption in Australia and the benefit of no transmission or distribution charges. Consumer use of rooftop solar has resulted in very low daytime demand for grid electricity in many states, leading to low daytime wholesale prices. Under these conditions, it is difficult to make new utility-scale projects economically viable without energy storage assets.

This challenge may be addressed over the next decade with the retirement of coal and increasing electrification of industry, homes, businesses and transport. However, developers of utility-scale projects will need greater certainty that there will be adequate demand and revenue available to make their business case stack up.

IT'S TIME TO STEP UP SUPPORT

Australia's governments, market bodies, developers, investors and innovators must commit to dramatically driving down the cost of solar PV. Reaching this ambitious goal will not only require work to address the barriers outlined above, but also further innovation to improve module efficiency and the way solar farms are designed and deployed.

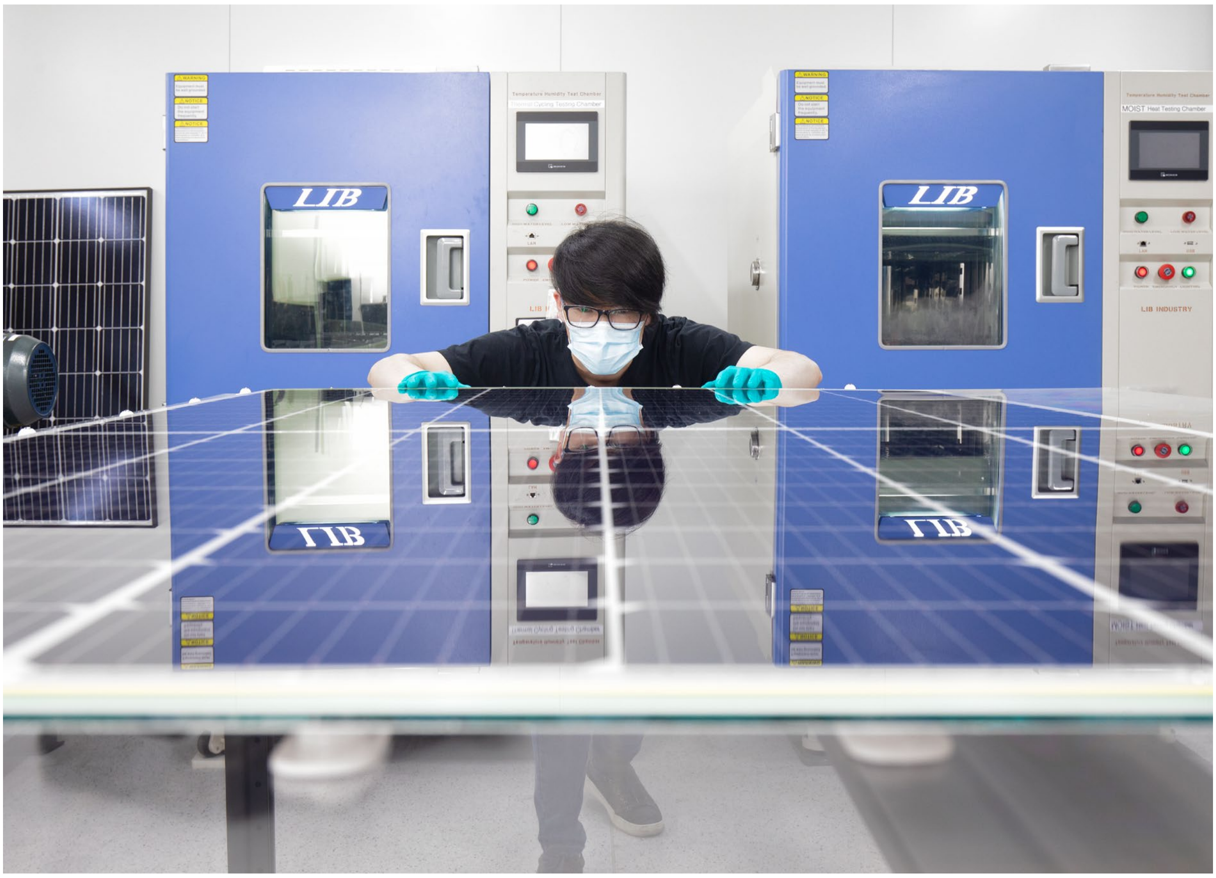
Ground-breaking research and development has been taking place in Australia's labs since the 1980s and we need to continue to build on this. Teams at UNSW, ANU, CSIRO and other research organisations are working on the breakthrough materials and methods that will unlock higher efficiencies. We must keep supporting and encouraging their work while ensuring there is a clear commercialisation path into mass manufactured panels for large-scale installations.

We know that some of the most innovative ways to install solar farms today are high-density fixed systems. However, this technology is not yet commercially competitive due to limited scale and a higher cost of capital, driven by its first-of-a-kind nature creating perceived risk among Engineering, Procurement and Construction (EPC) firms and investors.

To stimulate further innovation and accelerate the commercialisation of emerging technologies, Australia must support solar startups and encourage the best minds from adjacent fields to apply themselves to this challenge. ARENA recently supported 5B to develop its technology based on automation and pre-fabrication, and SunDrive, which has achieved a world record of 26.41 per cent cell efficiency in a commercial module. These opportunities are only the tip of the iceberg.

ARENA will continue to play a major role by investing in research and development and supporting the commercialisation of new technologies to achieve our 30-30-30 vision. To unlock this opportunity and address the critical enablers outlined above, there is a much broader set of actions that must be taken by other stakeholders across policy and regulation, market reform, innovation and investment.

The recently announced Solar Supply Chain Roadmap being undertaken by APVI will examine the barriers and opportunity for Australia to significantly upscale its solar PV supply chain. ARENA hopes this Roadmap can help catalyse an urgent conversation across various levels of Government regarding Australia's opportunity to realise ultra low-cost solar and the huge benefits this can unlock locally and globally.



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