Silicon to Solar

Foundations for Solar PV Manufacturing in Australia

AUSTRALIAN PV INSTITUTE

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About the Australian Photovoltaics Institute (APVI)

The APVI is a not-for-profit, member-based organisation providing data analysis, reliable and objective information, and collaborative research to support the development and uptake of PV and related technologies. The APVI and its predecessors have been operating since 1993. APVI members are organisations and individuals from industry and academia with an interest in solar energy research, technology, manufacturing, systems, policies, programs and projects.

APVI undertakes deployment and information-focused projects and produces detailed technical and market publications, hosts seminars, workshops, conferences and member events, prepares submissions on key solar issues and promotes solar energy in the media. Examples include annual reports on PV uptake, targeted information on PV deployment, assessments of PV potential in various sectors, and development of high quality solar analysis tools via the SolarMap. The APVI organises the annual Asia-Pacific Solar Research Conference, a regional forum for communicating outcomes covering all aspects of solar-related research. In addition to Australian activities, the APVI provides the structure through which Australia participates in two IEA Implementing Agreements: PV Power Systems (PVPS) and Solar Heating and Cooling (SHC) and manages the international PVPS Secretariat. A range of international data is collated, analysed and reported on through these programs. Diversified manufacturing is a now a key topic under both these Programs.

The S2S project has assessed whether parts of or the entire PV manufacturing value chain can be operational in Australia. For this project, the APVI partnered with the Australian Centre for Advanced Photovoltaics (ACAP), which is a key central agency to coordinate photovoltaic research activities in Australia.

Disclaimers

This report contains findings of the “APVI Silicon to Solar Study”. The Study was conducted by the Australian PV Institute (APVI) under the Australian Renewable Energy Agency’s Advancing Renewables Program in collaboration with the Australian Centre for Advanced Photovoltaics, Bright Dimension, ITP Renewables and Deloitte.

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Executive Summary

"Australia's biggest opportunity for growth and prosperity is the global shift to clean energy" according to the Australian Government[1]. For Australia to turn this opportunity into reality, the shift needs to be bold, decisive and starting now. Building a viable, relevant and timely solar photovoltaic (PV) manufacturing industry can (i) address the *risk* of energy dependency, (ii) provide a direct *return* in the form of investment, jobs, and new exports, and (iii) deliver a long-term *reward* by reversing the trend of Australia's decline in manufacturing while at the same time increasing Australia's economic complexity and labour productivity.

i. **Risk of energy dependency if Australia's clean energy future is not under its own control:** The target of net zero emissions by 2050 has now been accepted in Australia and around the world. Achieving this target, requires a rapid transition to renewable energy. For Australia, with its abundance of sunshine and land, this means that solar power will provide most of the future electricity generation. Australia is heavily reliant on the availability of PV modules, which are predominantly manufactured in China. Australia's forecast annual demand for solar modules of 5-15 GW in the near term is likely to see a substantial increase if Australia decides to transition its export industry to low-carbon intensity products, such as "green steel". This would mean that not only our transition to clean energy infrastructure would be dependent on a foreign nation, but also our broader export industry which, in future, will be powered by low-cost clean energy.

ii. **Return through investment, jobs and substituting some of the 250bn AUD[2] of carbon intensive energy exports:** Establishment of 25,000 t poly-Si domestic and export capability and 5 GW per annum integrated solar PV manufacturing capability from ingot to solar module would create over 4,000 direct, high-skilled, long-term jobs and see investments of around 2.4bn AUD in new state-of-the-art manufacturing capacity[3]. In parallel, solar exports via green products have the potential to replace Australia's current exports of coal and LNG, which will decline in a net zero world.

iii. **Reward by establishing a new state-of-the art manufacturing industry:** Australia's manufacturing capabilities have been in decline for decades and goods exported worldwide have become less and less complex in comparison to other nations.[4] Building a viable and relevant solar manufacturing industry would contribute to reversing this trend. This new industry would create an ecosystem for new solar technology developments and stop them being forced to go overseas, which has been the case for decades despite the fact that Australia is a world leader in solar cell research. It would also stimulate related manufacturing industries such as solar glass, energy storage, and recycling. In addition, it would support

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[1] Minister for Climate Change Energy Chris Bowen and Treasurer Jim Chalmers, https://ministers.treasury.gov.au/ministers/jim-chalmers-2022/media-releases/budget-boosts-australias-transformation-renewables, viewed 4 Oct. 2023

[2] According to the Office of the Chief Economist the export of coal, LNG and oil amounted to $249bn in the calendar year 2022, https://app.powerbi.com/view?r=eyJrIjoiODJlMTljZTMtZDgyZC00NGYwLTk4OTMtNzQ2ZmQxNjg4Y2I2IiwidCI6IjA3MDk5MWRkLWNkYjctNDc2Zi04MGRjLWU4YzNhOTFjNzBhZiJ9, viewed 4 Oct 2023

[3] Based on techno-economic analysis establishing 10 GW poly-Si capability and 5GW at ingot/wafer, cell and module manufacturing.

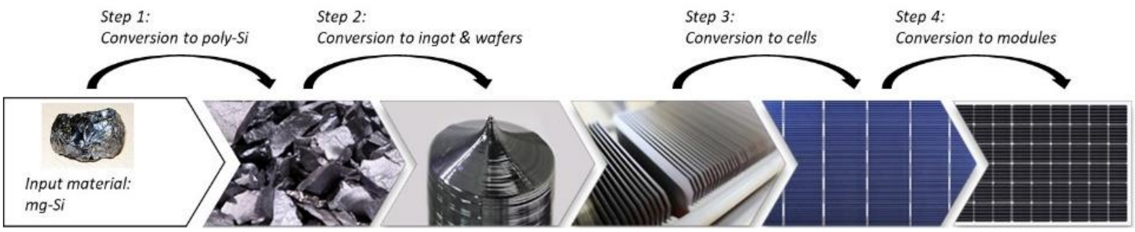
[4] Atlas of Economic Complexity (University of Harvard) publishes a ranking of countries based on how diversified and complex their export basket is. Countries that are home to a great diversity of productive know-how, particularly complex specialised know-how, are able to produce a great diversity of sophisticated products (https://atlas.cid.harvard.edu/rankings).

broader initiatives to lift the general skill set and expertise of the Australian workforce in important industries, such as the chemical, metallurgical and the semiconductor industries.

Establishing a solar manufacturing industry needs to satisfy the following three guiding principles:

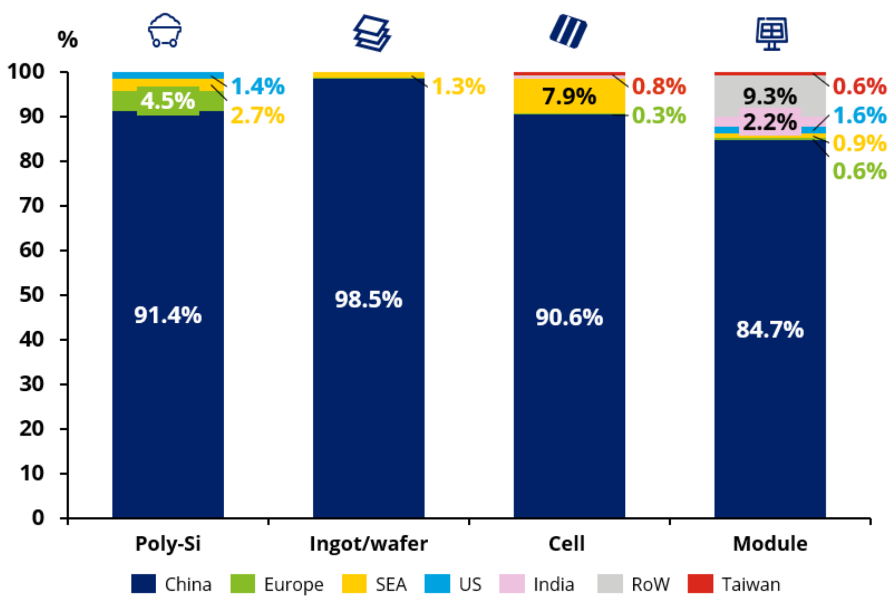
a) **Viable**: Each manufacturing step in the value chain set up in Australia needs to be globally competitive and economically viable long term.
b) **Relevant**: The manufacturing facility needs to have a scale that is appropriate and relevant for current and future Australian and global PV demand.
c) **Timely**: The manufacturing capacity needs to be set up within a timeframe that is necessary to achieve net zero by 2050.

The solar manufacturing industry is separated into five steps of which the ingot and wafer steps are usually combined as shown in the figure below. Goods can be shipped easily between each step, which allows for a globally diversified supply chain to be established in principle.



Solar value chain and conversion steps from metallurgical silicon (mg-Si) to solar module

Australia has existing manufacturing of metallurgical silicon (mg-Si), but the solar supply chain from polysilicon (poly-Si) to solar modules is strongly dominated by Chinese companies. The long-term Chinese commitment to establishing a domestic solar industry has led to a strong leadership position in terms of industry size, manufacturing cost and technology. Over the last two decades this has resulted in an astoundingly fast cost reduction of solar modules and substantial quality and performance increase, which has greatly benefited the deployment of solar energy around the world.



Market share in 2023 global PV manufacturing production by region and value chain segment

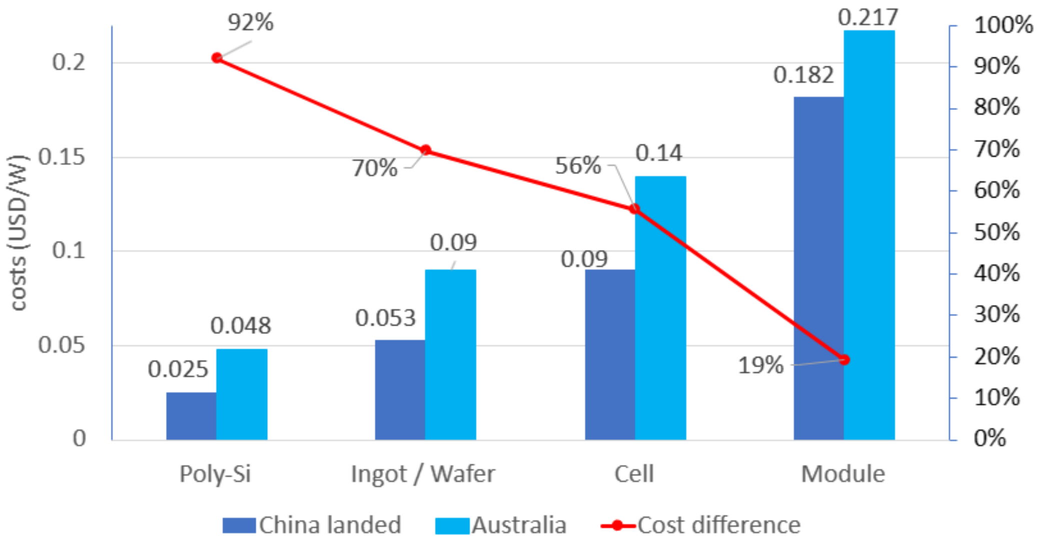
Many countries, however, are intervening in markets and rapidly shifting towards more aggressive green industry policy to support domestic manufacturing capability. The US, the EU and India have now implemented or are in the process of implementing industry policies that provide them with a greater control over solar PV supply chain through domestic production. In particular, the US with the Inflation Reduction Act (IRA) has taken unprecedented measures investing an estimated 369bn USD in "Energy Security and Climate Change".[5]

These economies are developing domestic manufacturing capability for reasons other than simple economic efficiency – reasons such as energy security, supply chain security, and the opportunity to become a first mover and capture value in future low carbon technologies that will be necessary in a globally decarbonised economy. Whatever initiatives are taken outside China to build a diversified supply chain, it is unlikely that they will even meet the respective domestic demands in the short to medium term. Australia's need for more control over the solar supply chain is not only motivated by domestic supply requirements, but even more importantly by the broader need to decarbonise its large export portfolio of goods (e.g., coal and gas) and replace it with exports of green steel, green ammonia and green hydrogen in the future. Any Australian initiative needs to be assessed in the context of programs by the trading partners. Australia has a chance to develop a solar industry that complements the efforts of our trading partners, without being dependant on their developments. This is particularly significant in the export market for poly-Si and ingot/wafer, where current support from other nations appears to be insufficient, and where concerns regarding human rights and technological concentration are most pronounced.

Based on the techno-economic analysis outlined in this report, any prospective Australian solar manufacturer will be faced with a significant economic disparity at every stage of the value chain in comparison to Chinese manufacturers. Even if the Australian entity procures its incoming products from the most cost-effective supplier, such as a manufacturer in China, a cost differential ranging from 20% to 100% persists. This is shown in the figure below[6].

[5] US Senate, "https://www.democrats.senate.gov/imo/media/doc/inflation_reduction_act_one_page_summary.pdf", accessed 17th Oct 2023.

[6] Note: The Chinese government has set solar energy as a long-term strategic focus and has provided consistent and material support to their manufacturing industry for twenty years. This support has delivered low cost, high efficiency and good quality solar modules to the world.



Graph shows Australian costs using previous input material procured in China and shipped to Australia vs cost of the landed good from China assuming large volume procurement in USD.

If Australia decides that solar manufacturing is a national, strategic priority, as in other countries have, Australia will need a **support framework** of active industry policies that closes the manufacturing cost gap to establish a viable and relevant solar industry in a timely manner.

The framework needs to encompass enabling, supply and demand policies which target industry development. A detailed analysis of the levelised cost of production (LCOP) was used to assess various policy options to establish a support framework with varying efficiency and effectiveness across the value chain. The analysis was complemented by extensive engagement with national and international stakeholders.

Several **enabling policies** were identified to be a prerequisite to create an attractive investment environment and overcome barriers at the project development phase. Without them, any direct or indirect financial support is unlikely to be effective in attracting private investment to Australian manufacturing. The identified critical enabling policies consist of ***priorities*, *permits*, *partnerships*, *people*** and ***provision of concessional finance***:

- ***Priorities***: Australia is competing on a global stage to attract international solar PV manufacturing capability and private investment. Industry stakeholders have repeatedly identified the need for certainty in the intention of federal and state governments to support the solar PV manufacturing sector as a strategic priority in the long-term. Clear and decisive signalling is needed, including explicit incorporation of solar PV manufacturing into funding mandates and strategies as a national priority.
- ***Permits***: Streamlined permitting and approval processes are required to overcome lengthy and unknown processing timeframes, particularly for the energy and chemical-intensive facilities required for poly-Si, ingot/wafer and cell manufacturing. This should include provision of a targeted pre-approval engagement service, provision of sector-specific guidance, accelerated processing timeframes and increased coordination between government agencies. Additionally, the government can facilitate place-based rather than project-based environmental planning at strategic industrial hubs.

- *People*: Prospective solar PV manufacturers anticipate challenges with regards to attracting and retaining an appropriately skilled manufacturing workforce in Australia. Governments should ensure streamlined visa pathways exist for solar PV manufacturing workers in the short term, while developing specific worker reskilling support and training programs in parallel. Visas for employees of partnerships/joint ventures (JVs) could be linked to training requirements to upskill the domestic workforce in preparation for the future manufacturing operations (refer below).
- *Partnerships*: Australia does not currently possess the expertise necessary to establish manufacturing capability at any stage of the value chain at a relevant scale, and international operating partners will likely be required to provide technology IP, equipment, setup, and initial training of the domestic workforce. However, both international and Australian companies have indicated high uncertainty around foreign investment approvals in Australia with regards to both timing and outcome. Early engagement between industry and government on the feasibility of international partnerships will be key for success in establishing domestic solar PV capability.
- *Concessional finance*: The development of any element of the solar value chain in Australia will require significant amounts of capital, particularly at the upstream end of the value chain, i.e., poly-Si and ingot/wafer production. Concessional finance from the government in the form of loans or equity will assist in 'crowding-in' private capital and demonstrate to the private sector that Australia intends to become a material participant in the domestic and global solar market. Whilst concessional finance in itself is not sufficient to start the new industry, it is seen as a necessary pre-requisite to catalyse national and international co-investment.

Demand policies: The government has several options to increase offtake and demand certainty for locally produced products through the adoption of a mechanism similar to the Renewable Energy Target (RET) coupled with local content incentives, direct government procurement with mandated degrees of local content and other mechanisms discussed in this report. Whilst demand-side policies alone will not be sufficient to stimulate a domestic solar manufacturing industry at scale, they can send a powerful signal in combination with other mechanisms and effectively address the offtake risk barrier. In addition, the Australian government should also actively set up strategic partnerships with other jurisdictions to build up shared supply chains for solar modules, similar to other green technologies such as the Australian and German Hydrogen Accord.[7]

Supply policies: Production credits are an effective mechanism to stimulate industry growth and narrow the cost gap to imported products for Australian manufacturers across the value chain. They are also a policy mechanism that would, homogenously applied across the value chain, achieve the desired outcome. Globally, production-linked incentives have been very effective at attracting industry investment and scaling solar PV production, the most prominent recent examples of this type of support are the US Inflation Reduction Act (IRA) and the Indian Production-Linked Incentive Scheme (PLI). Within Australia, a production credit mechanism is currently being rolled out for hydrogen under

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[7] DEECCEW, https://www.dcceew.gov.au/about/news/australia-and-germany-strengthen-hydrogen-partnership#:~:text=HyGATE%20was%20committed%20to%20under,technology%20innovation%20in%20the%20industry , viewed 19th Oct 2023.

the Hydrogen Headstart Program. The mechanism can require a lot of direct financial support, however the main benefit of production credits for government is that they work on a payment-on-results basis, therefore cost to government is only incurred if production eventuates. Options to mitigate potential risks can be addressed through appropriate policy design as discussed in this report.

Both upfront capital and ongoing operational support are needed at each step of the value chain to overcome critical barriers and establish a solar manufacturing industry. Modelling as part of this study indicates this can be achieved through the combined impact of concessional finance and implementation of a production credit at each step of the value chain. Both of these support levers can leverage and/or build on existing processes, funds or programs that the Australian government has announced, such as the National Reconstruction Fund and the Hydrogen Headstart program. A wide range of other levers have been assessed and could contribute. While each of them is effective at targeting certain barriers identified, such as high upfront capital and high electricity prices, each lever in isolation cannot effectively close the cost gap. However, alternative combinations of support levers discussed in this report could also support the development of an Australian solar industry if the various support levers in combination are tailored specifically for each step in the value chain.

A summary of a combination of concessional loans and production credits at each step of the value chain is provided below.[8] The 0% concessional loan was chosen to clearly show the impact at one end of the spectrum of interest rates.

Summary of (a) production credits necessary to bridge the costs gap to manufacturing in China together with a concessional loan, and (b) 10-Year total (discounted) support needs for 10 GW poly-Si + 1 GW ingot/wafer, cell, and module production, and 10 GW poly-Si + 5 GW ingot/wafer, cell, and module manufacturing targets.

Production Step	Production credit	Concessional loan	Total support required over 10-year period for combined impact (discounted)[9]	
			Minimum viable scale 10 GW of poly-Si 1GW of Ingot/wafer, cell and modules	*Target scale* 10 GW of poly-Si 5GW of Ingot/wafer, cell and modules
Poly-Si[10]	9 AUD/kg (6.5 USD/kg)	0% interest	2.1bn AUD	2.1bn AUD
Ingot & wafer	11 AUD/m^2 (7.5 USD/m^2)	0% interest	350m AUD	1.8bn AUD
Cell	6.5 AUDc/W (4.2 USDc/W)	0% interest	459m AUD	2.3bn AUD

[8] The total cost of the concessional loan component is considered a loss in revenue from provision of a 0% interest rate loan.
[9] Exchange rate used for USD to AUD: 0.7045 USD/AUD (average of 2023/4 to 2026/7, Deloitte Access Economics, July 2023, https://www.deloitte.com/au/en/about/press-room/business-outlook.html). Minor discrepancies may exist due to rounding of the numbers.
[10] For polysilicon, this assumes removal of the mg-Si anti-dumping tariff on Chinese imported mg-Si.

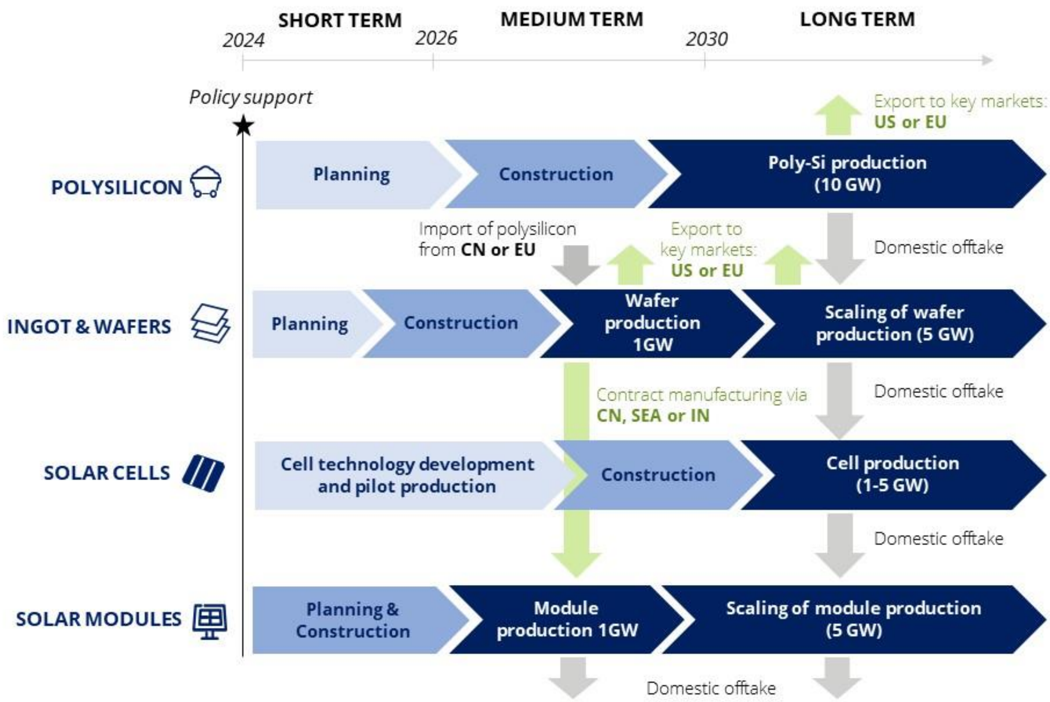
Module	4.6 AUDc/W (3.0 USDc/W)	0% interest	317m AUD	1.6bn AUD
Total estimated support for the full value chain over a 10-year period (discounted)			~3.2bn AUD	~7.8bn AUD

Any direct financial support should be clearly linked to well defined assessment and/or eligibility criteria, to ensure use of public funds delivers benefit sharing with the Australian public. In addition, policy design should consider alignment with broader sustainability and social license objectives, such as delivering emissions reductions, encouraging continuous innovation, ensuring a just transition for traditional energy communities, and embedding circularity principles.

Ultimately which steps in the value chain are supported by the Australian government will depend on additional distinct considerations:

- If **poly-Si manufacturing** is set up domestically, Australia can be part of a globally diversified supply chain exporting particularly to the rapidly growing US and EU markets. Australia would export renewable energy-intensive value-added products and have direct control over poly-Si for the needs of the domestic solar market. This would mean that Australia would start "soaking up its abundant natural solar resource" by manufacturing energy intensive goods for export.
- **Ingot & wafer manufacturing** addresses the most concentrated step in a single country in the solar supply chain. Australian wafers could be exported to the US, EU and other regions. Contract manufacturing overseas could enable domestically produced wafers to be converted to cells and modules used in local solar systems.
- Rapid development of **cell technology** and large production capacity in China, the US and India present a challenge to setting up viable cell production domestically. Australia's strong track record in cell research could lead to cutting-edge production in the future. However, R&D, prototyping and pilot lines require additional time.
- **Module production** represents a "low-hanging fruit" option due to relatively simple technology, as well as relatively low upfront investment and government support needed. However, building globally relevant and competitive module production is very challenging, and Australian made modules would likely predominantly be deployed domestically.

If Australia adopts a comprehensive industry policy framework to develop the solar manufacturing industry to address the risk, reap the return and benefit from the reward discussed above, manufacturing capacities across the value chain could be established as shown in the figure below.



Roadmap for the development of an Australian solar manufacturing industry integrated into a globally diversified supply chain with the US, EU, India, China and SE Asia.

The development of a solar industry of 10 GW of poly-Si and 1 GW of ingot/wafer, cell and module capacity is credible as the minimum viable scale. However, it is recommended to set a target of 5 GW or above to meet a sizeable share of Australia's future domestic demand and grow the industry to a scale that is internationally relevant as a whole.

The roadmap developed in the S2S study would lead to an Australian solar manufacturing industry if the recommended initiatives and policies listed below and discussed in this report are implemented. The following concrete actions by government will be needed to ensure a successful industry development:

Immediately

- Declare solar PV manufacturing industry a strategic priority
- Determine government alignment with the solar value chain development roadmap outlined in this report
- Set up a Solar Manufacturing Taskforce to implement and deliver next steps and recommendations

Next 12 months

- Prioritise roll out of enabling support for people, permits and partners
- Develop implementation structure to allocate and deliver financial supply-side support (concessional finance and production credits)
- Design frameworks for demand-side support (government procurement, circular economy and local content incentives)
- Continue to remove barriers for accelerated solar PV deployment
- Strive for broad political support

- Secure budget for the selected framework of subsidies

Years 1 – 5

- Implement concessional finance and production credit support for 10 years of facility operation (or alternative policy levers as appropriate)
- Start government procurement
- Introduce local content incentives
- Continue R&D support
- Consider the provision of targeted support on electricity price guarantee
- Consider the provision of additional up-front capital support
- Implement a RET-like mechanism of mandated solar PV installations

Summary of recommended initiatives and policies

#	Subject	Recommendation
Enabling actions & policies (see Section 5.2 for details)		
1	Priorities	Announcement / recognition of solar PV manufacturing as a strategic government priority
2	Permits	Provide clear upfront guidance and streamlined processes for permitting and approvals
3	Partners	Provide clear and early direction on joint ventures or partnerships with foreign investors
4	People	Short term: Ensure streamlined visa pathways exist for solar PV manufacturing workers in the government's renewed Migration Strategy. Short – medium term: Develop specific worker reskilling support and training programmes
5	Concessional finance	Facilitate highly concessional finance (equity, loan or guarantees) to secure upfront capital investment.
Demand-side actions & policies (see Section 5.3 for details)		
6	Demand-side certainty	Short to medium term: Announce commitment to government procurement and implement processes on both federal and state level that favour local module procurement. Medium to long term: Implement a form of local content incentive/bonus
7	Facilitate demand for Australian exports	Facilitate preferential trade arrangements with key economies for solar PV components Remove barriers for low-carbon production of poly-Si and ingots/wafers to ensure success of Australian exports in target EU and US markets and minimise the impact of future carbon tariffs
8	Facilitate domestic deployment	Short term: Remove barriers to utility-scale solar PV deployment Encourage solar PV installation
Supply-side actions & policies (see section 5.4 for details)		

9	Production credits	Implement a production credit scheme in combination with concessional finance to close the cost gap to imported products in the value chain steps where appropriate
10	Alternative and additional supply side support	Electricity price guarantee Upfront capital support Continued R&D support
Key eligibility considerations for support policies (see Section 7.2.8 for details)		
11	Decarbonised electricity supply – 'additionality'	Subsidisation linked to decarbonised electricity requirements. Renewable electricity for a facility should be additional and dedicated to the extent possible, to not detract from existing electrification and decarbonisation efforts.
12	Worker reskilling and training	Financial support for new facilities should be linked to worker reskilling and training
13	PV recycling and circular economy requirements	Financial support given to solar PV manufacturers can be coupled with eligibility requirements to develop or support capabilities for PV recycling
14	Locating in areas transitioning away from a fossil-fuel based economy	Financial support should include eligibility criteria or incentives to encourage locating in areas affected by the energy transition
15	Repayment clause and consumer price protection	To protect the use of taxpayer money, provision of support may be linked to a repayment clause should a minimum operational period or production period not be met

1. Introduction

This report is organised into seven main sections. In the present section (**Section 1**), a foundational argument underscores the ***risks*** if domestic solar PV manufacturing is not developed in a timely, viable and relevant manner. It also highlights the expected long-term economic ***returns*** from active participation in this industry and emphasises the substantial broader ***rewards*** that await Australia in the long run through the establishment of solar PV manufacturing.

Section 2 presents a detailed analysis of the global and domestic PV market dynamics. By examining market projections for 2030 and 2050, both on a global scale and within the context of Australia's ambitious renewable energy targets, this section aims to provide a comprehensive perspective on the market's growth potential. Additionally, the section examines the current state of PV supply across the value chain, giving special attention to global manufacturing capacity.

Section 3 provides an in-depth assessment of the PV value chain from poly-Si to modules. It analyses production requirements, material flows, utilities, labour and offers a comparative evaluation of production costs in Australia versus China at each manufacturing stage to provide a comprehensive understanding of their economic feasibility.

Section 4 addresses practical aspects of PV manufacturing in Australia, evaluating critical factors such as volume, production timelines, sustainability considerations, Australia's competitive advantages, and potential barriers. This section also sets the stage for informed decision-making regarding the localisation of the various PV manufacturing steps in Australia. Additionally, this section discusses end-of-life options for PV panels, covering recycling, technical approaches, and economic considerations relevant to Australia.

Section 5 focuses on policy assessments critical for enabling and catalysing PV manufacturing in Australia. It evaluates various policy options and principles, covering permitting, foreign investment guidelines, labour considerations, and other enabling factors. Demand-side policies, including government procurement guarantees and local content incentives, are discussed, as are supply-side policies like production-linked support, concessional loans and electricity price guarantees. This comprehensive assessment offers a roadmap for policymakers to facilitate and sustain a domestic PV manufacturing industry.

Section 6 analyses different pathways for developing a solar industry in Australia and develops recommendations for a specific approach based on the analysis in this report.

Section 7 synthesises findings and recommendations from preceding sections to outline a strategic participation for Australia in the PV value chain. It presents policy recommendations to successfully unlock a domestic PV manufacturing industry of relevant capacity in Australia. Critical requirements, demand-side support, financial backing and eligibility considerations for support are highlighted. Finally, a credible roadmap for realising this vision capturing key steps and milestones, is presented.

1.1. The Role of PV in Meeting Net Zero Targets

A key driver for current and future solar photovoltaic (PV) deployment in Australia and around the world is heading towards net-zero carbon emissions by 2050. Australia's target is a 43% reduction in greenhouse gas emissions against 2005 levels by 2030 and net zero by 2050,[11] which is similar to the target for the European Union.[12] The respective US target is slightly more aggressive, with a 50 – 52% reduction by 2030.[13] China's short term target is even more aggressive at 65%, although the longer term target specifies that China will not reach net-zero until 2060.[14]

Australia's exit from carbon intensive electricity generation is well on its way, as demonstrated on 28th April 2023 when the last coal-fired power generation unit at AGL's Liddell Power Station was switched off.[15] The decommissioned generation capacity will be replaced with solar, wind and hydro power, combined with battery and hydrogen storage to ensure the necessary firming capacity. However, Australia's ambitions go beyond replacing the existing fossil-fuel power generation with renewable energy. According to recent announcements, the Parliament of Australia is "focusing on identifying challenges and opportunities for Australia to capitalise on our abundant natural resources to drive economic growth, create new industries and jobs and become a green energy superpower".[16] In the future state of a green energy superpower, Australia will export renewable energy directly via cable, indirectly via hydrogen or other forms of energy storage and also embodied within low carbon products manufactured in Australia. It will manufacture green steel, green aluminium, green ammonia and other goods utilising abundant renewable energy. In addition, increased electrification of general manufacturing processes as well as domestic appliances like water heating, cooking and charging of electric vehicles will increase Australia's electricity demand.

1.2. The Risks of a Concentrated Solar PV Supply Chain for Australia

The core value chain segments in the manufacturing process of solar modules, after the generic production of metallurgical Silicon, can be divided into five conversion steps of which the ingot and wafer steps are usually combined. These steps are shown in Figure 1-1 and analysed in detail in Section 30.

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[11] Australian Government, https://www.aofm.gov.au/sites/default/files/2022-11-28/Aust%20Govt%20CC%20Actions%20Update%20November%202022_1.pdf, viewed 15th May 2023.
[12] UNFCCC, https://unfccc.int/sites/default/files/NDC/2022-06/EU_NDC_Submission_December%202020.pdf, viewed 15th May 2023.
[13] The White House, https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/, viewed 15th May 2023.
[14] UNFCCC, https://southeastasia.hss.de/download/publications/44_-_2022_Overview_of_climatechange_mitigation_efforts_221102.pdf, viewed 15th May 2023.
[15] Energy Magazine, https://www.energymagazine.com.au/liddell-power-station-shut-down-after-52-years-of-operation/, viewed 28th April, 2023.
[16] Parliament of Australia, 18th Oct 2022, https://www.aph.gov.au/About_Parliament/House_of_Representatives/About_the_House_News/Media_Releases/Australias_transition_to_a_green_energy_superpower, viewed 12th May 2023

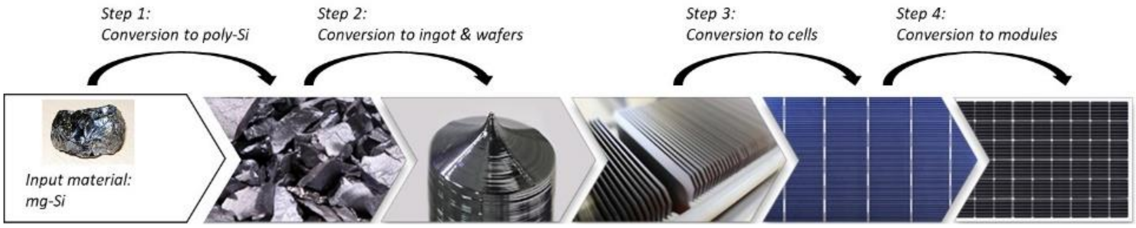

Figure 1-1: Solar value chain and conversion steps, adapted from Bernreuter[17]

In summary:

- **Step 1 – Poly-Si purification**: The metallurgical Silicon (mg-Si) as the input material is purified via a chemical gasification and vapour deposition process to poly-Si.
- **Step 2 – Ingot/wafering**: The poly-Si is converted via a melting and crystal growth process to ingots, which are subsequently cut into thin wafers (the ingot and wafering processes are generally co-located and seen as one processing step).
- **Step 3 – Cell conversion**: The wafers are converted using semiconductor processing to solar cells.
- **Step 4 – Module conversion**: The solar cells are assembled into solar modules.

Currently, the manufacturing value chain for solar modules is highly concentrated within China and Chinese owned companies (Figure 1-2).

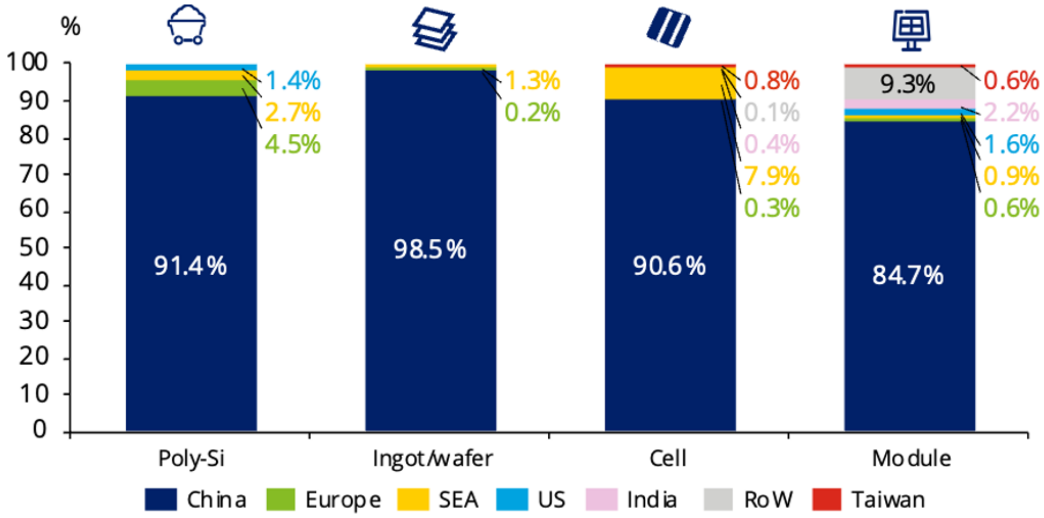

Figure 1-2: Market share in 2023 global PV manufacturing production by region and value chain segment

The extremely high concentration represents a risk for Australia's decarbonisation plans and its ambition of becoming a renewable energy superpower. In 2022, 3.9GW[18] of solar power generation was installed in Australia. Almost all solar modules installed in 2022 were imported from overseas, with less than 30 MW (<1%) manufactured in Adelaide by Tindo Solar from imported solar cells[19].

[17] Bernreuter, www.bernreuter.com/solar-industry/value-chain/ , viewed 22nd Aug. 2023
[18] Australian Energy Council, "Solar Report Quarter 1, 2023", April 2023.
[19] Information provided by manufacturer, new manufacturing facility was ramped up during this period.

Electricity is fundamental to Australia's economy, and its future state of electricity generation from renewable energy is almost entirely dependent on product supply from China.

Australia has three levers to manage this risk of concentration in the supply chain:

i. **Depend on China:** China is currently, and predicted to remain in the future, the largest manufacturer and user of solar modules[20]. There are numerous reasons why a continuous dependence on only China as a supplier carries high risk, such as supply disruption due to natural disasters, internal energy market issues, pandemics and geopolitical tensions. Some of these are being addressed by Chinese companies through operating manufacturing facilities in different countries. However, China itself has very ambitious decarbonisation targets, and Australia's demand for about 5 GW p.a. of solar modules, compared to global production of about 1,000 GW p.a. in the near future, means that Australia has very little bargaining power in the global competition for economically priced solar modules. Whilst Australia will continue to purchase solar modules from China in the foreseeable future, any disruption in this set-up of the supply[21] would mean a direct impact on Australia's transition to renewable energy.
ii. **Others solve the issue**: Australia can hope to diversify the supply of solar modules from other regions, like the US, Europe, India and others. Many countries have recognised the critical situation in the solar supply chain and have acted by developing initiatives to set-up a local supply chain, most notably in the US through the Inflation Reduction Act (IRA). The IRA contains USD 369 billion for climate change mitigation[22]. The IRA contains direct solar manufacturing tax credits with targeted support for solar-grade polysilicon (poly-Si), wafer, cell and module manufacturing (See also Section). Similarly, the European Commission announced in March 2023 the "Net-Zero Industry Act: Making the EU the home of clean technologies manufacturing and green jobs"[23] as a part of the Green Deal Industrial Plan. India directly targets solar manufacturing through the Production-Linked Incentive (PLI) scheme[24]. From an Australian perspective, these announcements might lead to new supply lines. However, it still needs to be proven how quickly these capacities can be built[25] and whatever new manufacturing capacity is installed in these regions will still not meet the total local demand for solar power generation.
iii. **Take some control back**: Australia had solar cell manufacturing capability until 2012[26] and has a globally recognised track record in solar technology development. The PERC[27] cell technology used in most commercial solar modules today and the increasingly popular

[20] PV Cell Tech, "PV Manufacturing & Technology Quarterly Report", April 2023.
[21] Note that during the Covid pandemic, module supply to Australia was severely impacted. Between the end of 2020 and the end of 2021 global module shipping costs alone rose to over 50%, (https://colitetech.com/blog/why-is-the-cost-of-solar-increasing/).
[22] PV Tech, https://www.pv-tech.org/an-ira-deep-dive-how-significant-is-it-and-what-uncertainties-remain/ , 5th Jan 2023
[23] European Commission, https://ec.europa.eu/commission/presscorner/detail/en/IP_23_1665, viewed 4th May 2023.
[24] PV Magazine, https://www.pv-magazine.com/2022/11/22/india-launches-second-phase-of-incentive-scheme-for-solar-manufacturing/ viewed 4th May 2023
[25] PV Tech, https://www.pv-tech.org/meeting-us-solar-needs-with-domestic-equipment-will-be-challenging-woodmac-details-iras-impact-on-manufacturers/, viewed 4th May 2023
[26] Renew Economy, https://reneweconomy.com.au/silex-systems-closes-homebush-solar-pv-manufacturing-plant-93963/, viewed 4th May 2023.
[27] Passivated Emitter and Rear Cell (PERC)

TOPCon[28] technology are both based on inventions made at the University of New South Wales, Sydney[29]. If solar manufacturing across the value chain is set up in Australia, it would mitigate the supply risk and increase Australia's resilience to manage the transition to a renewable energy future.

To successfully navigate this transition, all the three levers of risk management highlighted above will need to be set and adjusted carefully over the coming decades. If Australia focuses on a single lever while ignoring the other two, the transition will likely fail. Only a fruitful collaboration between Australia, China and the other regions that build out their solar manufacturing capacity can provide the speed and targeted approach necessary to transition to a world powered by renewable energy as quickly as is required. Australia will need to find a way to manage a reliable, economical supply of quality solar modules by setting these three levers appropriately.

1.3. Benefits of a Domestic Solar PV Supply Chain

Economic **Return**: Bringing the manufacturing of solar PV panels to Australia can bring about several short-term advantages. This includes the creation of more than 4,000 new, highly skilled jobs in a brand-new industry focused on renewable energy and semiconductor technology. Additionally, it will deploy an investment of 2.4 bn AUD in cutting-edge manufacturing facilities, which will help secure a degree of control over the medium-term supply of solar panels.

From a broader perspective, Australia is one of the world's largest energy exporters at present[30]. Australia's exports of fossil fuel (coal, LNG), valued at about AUD 250 billion in 2022, will decrease in a transition to a decarbonised global economy. This means that Australia will need to develop substitute products for export markets by producing environmentally friendly value-added products such as green steel, aluminium, and hydrogen; "soaking up" its abundant solar and wind resources. Australia is also the world's largest exporter of iron ore[30] , which in turn requires enormous amount of energy for the smelting process to manufacture steel. This energy will need to come from renewable energy resources in a decarbonised world, and Australia is in a good position to develop local processing if it also develops its solar generation capacity. The transition of Australia's domestic energy needs and energy exports to renewable energy is essential for Australia's future as a strong and healthy economy.

Long-term **Reward**: Establishing large-scale, sustainable solar manufacturing will significantly enhance Australia's economic complexity. It will also create an ecosystem that will facilitate the rapid scaling and deployment of advancements in solar technology, transitioning from laboratory research to large-scale fabrication and thus become an efficient cleantech innovator[31]. Furthermore, it offers a chance to

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[28] Tunnel Oxide Passivated Contact (TOPCon)

[29] Queen Elizabeth Prize for Engineering, https://qeprize.org/winners/martin-green, viewed 29th May 2023.

[30] World ranking: 1st for metallurgical and 2nd for thermal coal as well as 1st for iron ore according to the Office of the Chief Economist, June 2023, "Resource and Energy Quarterly" and 1st for liquified natural gas (LNG) according to Statistica, https://www.statista.com/statistics/1262074/global-lng-export-capacity-by-country/, viewed 22nd Aug. 2023

[31] Cleantech Group, 'Global Cleantech Innovation Index (GCII)', https://www.unido.org/sites/default/files/files/2017-11/GCII_GCIP_report_2017.pdf, 2017.

retrain and transition the workforce from fossil fuel-based industries to renewable energy-based sectors.

These factors will not only strengthen Australia's economic resilience but also enhance its technological expertise, thereby increasing its contribution to global efforts to reduce carbon emissions.

1.4. Setting Up Viable, Timely and Relevant Manufacturing in Australia

This study assesses how **Lever 3– 'Take some control back'** (as described in Section 1.2) can be set, so that Australia develops a credible future state in which potentially some or all steps in the solar value chain are manufactured on shore. Any initiatives taken in this regard will be set within the context of the other 2 levers: to secure solar module supply (Lever 1 – 'Depend on China' and Lever 2 – 'Others solve the issue').

This credible future state is assessed along three core principles:

a) *Viable*: The manufacturing step in the value chain needs to be globally competitive and economically viable long term.
b) *Relevant*: The manufacturing facility needs to have a scale that is appropriate and relevant for future Australian and global PV demand.
c) *Timely*: The manufacturing capacity needs to be set up within a timeframe that is necessary to meet 2030 emission reduction targets and to achieve net zero by 2050.

An assessment of the inherent competitive advantages unique to Australia, which provide additional values for onshore processing and ensure long-term sustainable competitiveness has also been included. To meet the timeliness criteria, the credible future state drafted by this study will only rely on state-of-the-art manufacturing processes that have a Commercial Readiness Index (CRI) of 5 or higher[32].

The S2S study will not provide an exhaustive review of all *possible* onshore manufacturing scenarios but instead focuses on one *credible* scenario to show the possibility and likelihood of this future state. This ensures that the credible future state can be achieved within a necessary timeframe and at a scale that is relevant without carrying undue commercial and/or technology risks. Nevertheless, once Australia has an established solar supply chain, new technologies will find it easier to enter the market as they will benefit greatly from the ecosystem developed through setting up large-scale solar manufacturing locally. Hence, the technology choices proposed in this study will aim to provide a manufacturing baseline into which future new technologies can be integrated once they reach the commercial readiness level required.

Each step in the value chain from poly-Si to solar module is assessed using a Techno-Economic Analysis (TEA) framework and paired with business and policy analysis. The TEA was carried out against 24 criteria including main technology, alternative technology, key players, IP consideration,

[32] ARENA, "Commercial Readiness Index for Renewable Energy Sectors", published Feb. 2014

input / output material flow, key equipment and suppliers, investment costs, operational costs, labour and skill requirements, logistics, environmental considerations, social licence, transfer of skills, amongst others as discussed in Section 3 of this document. The results of the TEA form the basis for the business and policy analysis which is guided by the key principles of *viability, relevance and timeliness.*

2. Market Analysis: Foundations for Solar PV Manufacturing in Australia

This section focuses on evaluating both local and global projections for annual PV demand and manufacturing capacity up to 2050. The goal is to establish the necessary growth trajectory and determine the quantity and timing of solar PV required. The outcomes of this market analysis then guides the assessment of the appropriate manufacturing scale that Australia will require.

Additionally, this analysis provides an overview of the current global supply chain, identifies existing capacities in Australia, gauges industry interest in entering the market, and defines the scope of the technologies that will serve as the baseline for the bottom-up cost analysis of the techno-economic assessment. The chosen technology will primarily be based on the most likely and widely manufactured silicon wafer-based solar cell technology, ensuring alignment with the three key assessment principles. Furthermore, this study does not explicitly assess metallurgical silicon (mg-Si), the raw material used for poly-Si purification. This omission is due in part to the more diversified landscape of the mg-Si supply chain, with over 30% sourced from outside China. Additionally, Australia already has an onshore mg-Si manufacturer, Simcoa, located in Western Australia, boasting a production capacity of 52,000 t.[33] This capacity already exceeds Australia's requirements for its own solar demand. Similarly, its production has already been considered in other recent studies that focus on critical energy minerals related to renewable energy[34].

2.1. PV Market Projections 2030 & 2050

2.1.1. Global Projections

Globally, the solar PV market is forecast to continue growing rapidly, driven by declining costs, increasing demand for renewable energy, and supportive government policies. The International Energy Agency (IEA) in its Net Zero by 2050 scenario[35] projects that total installed solar PV capacity could reach 4.8 TW by 2030 and 14.5 TW by 2050. However, in the past, IEA's WEO has consistently underestimated the growth of solar energy globally, as reduced costs and improvements in policy support have exceeded expectations. In 2022 alone, the total global installed PV capacity grew by approximately 360 GW, surpassing IEA's expectations of a 190 GW increase[36]. Solar energy has become increasingly competitive with traditional fossil fuels, and technological advancements have made solar modules more efficient and affordable than most other renewable sources. The anticipated solar PV demand in the global energy markets for the years 2030 to 2050 is highly variable, with estimates ranging from 30% to 70% of the total power generation. Figure 2-1 illustrates instances of this, with BNEF's 2021 NEO Green Scenario and the ITRPV broad electrification scenario presented as the minimum and maximum estimates for the annual global demand for PV, respectively. In addition, it shows the conservative scenario of global PV demand from the Chinese PV Industry Association (CPIA) and the forecast of module supply shipments reported in the quarterly PV Tech Research report.

[33] SIMCOA, https://www.simcoa.com.au/company, viewed 9th May 2023
[34] CSIRO, " Critical Energy Minerals Roadmap", published 2021. CSIRO, "Australian Silicon Action Plan", published 2022.
[35] IEA, "World Energy Outlook 2022", October 2022.
[36] IEA, "Renewable Energy Market Update", May 2022.

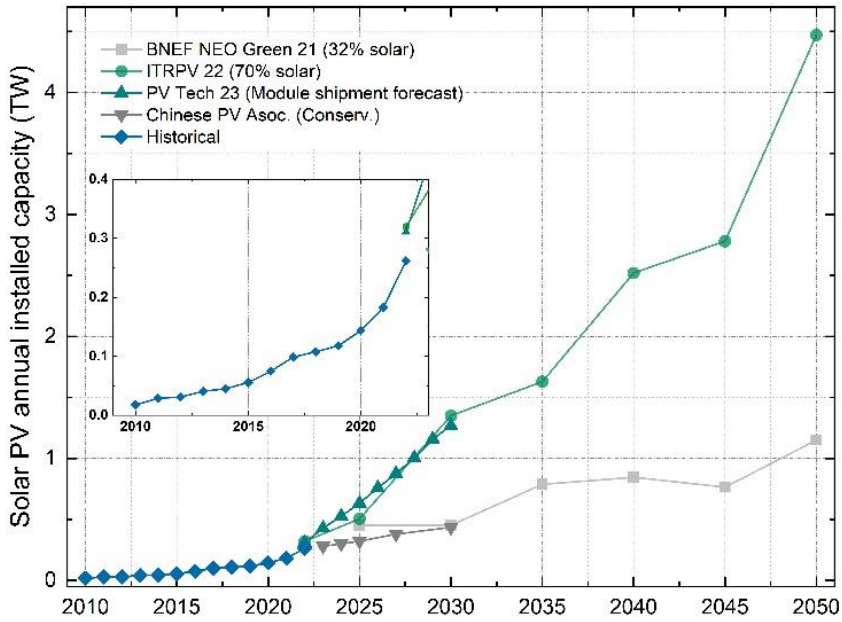

Figure 2-1: Global Solar PV annual demand forecast. Sources: PV Cell Tech[37], BNEF[38] , ITRPV[39] and CPIA[40].

Considering historical trends and current projections, and for the purpose of this work's analysis, it is anticipated that the annual global demand for solar PV will continue to increase to perhaps around 1 TW by 2030 and conservatively around 2 TW by 2050. Such a scenario is more optimistic than that projected by BNEF, although more conservative than the ITRPV full-electrification scenario. If the ambitious electrification plan presented in the 2022 ITRPV report becomes a reality, which includes goals such as widespread adoption of clean energy, reduced energy consumption, accessible fresh water, and affordable power, the annual capacity additions could more than double by 2050, reaching around 4.5 TW per year (accumulating to over 63 TW of total installed capacity).

2.1.2. Australian Renewable Energy Targets

In Australia, the government has set a target of achieving 82% of electricity from renewable sources by 2030,[41] resulting in a substantial expansion of the PV industry. In 2022, over 3 million Australian households have rooftop solar panels, and the total installed capacity reached approximately 30 GW. AEMO predicts that in the next two decades, annual PV additions will range between 4 and 8 GW, according to their "Step Change Scenario" – the most probable scenario outlined in the 2022 AEMO ISP. This would lead to a total installed capacity of around 100 GW by 2050. Similarly, according to AEMO's "Hydrogen Superpower Scenario", if Australia is to realise its ambition of becoming a hydrogen superpower, the annual growth of PV capacity should double the current rate by 2025 and reach 15 GW per year by 2045, resulting in a cumulative capacity of approximately 300 GW by 2050

[37] PV Cell Tech, "PV Manufacturing & Technology Quarterly Report", April 2023.
[38] BloombergNEF, "Solar PV Trade and Manufacturing: A Deep Dive", Feb. 2021.
[39] VDMA, "International Technology Roadmap for Photovoltaic (ITRPV) – 2021 Results", Mar. 2022.
[40] CPIA, "China PV Industry Development Roadmap", April 2023.
[41] Australian Government, https://www.globalaustralia.gov.au/industries/net-zero#:~:text=Rewiring%20the%20Nation%20provides%20A,82%20per%20cent%20by%202030 , viewed 12th May 2023.

(See Figure 2-2). Nonetheless, there are more ambitious scenarios not depicted in Figure 2-2. For instance, according to ARENA's *Ultra Low Cost Solar* white paper[42], there is potential for over 1 TW of PV installations by 2050, equating to an annual installation rate exceeding 37 GW. Similarly, Net Zero Australia's analysis anticipates 1.9 TW of PV capacity by 2050, translating to an annual installation rate of 70 GW[43].

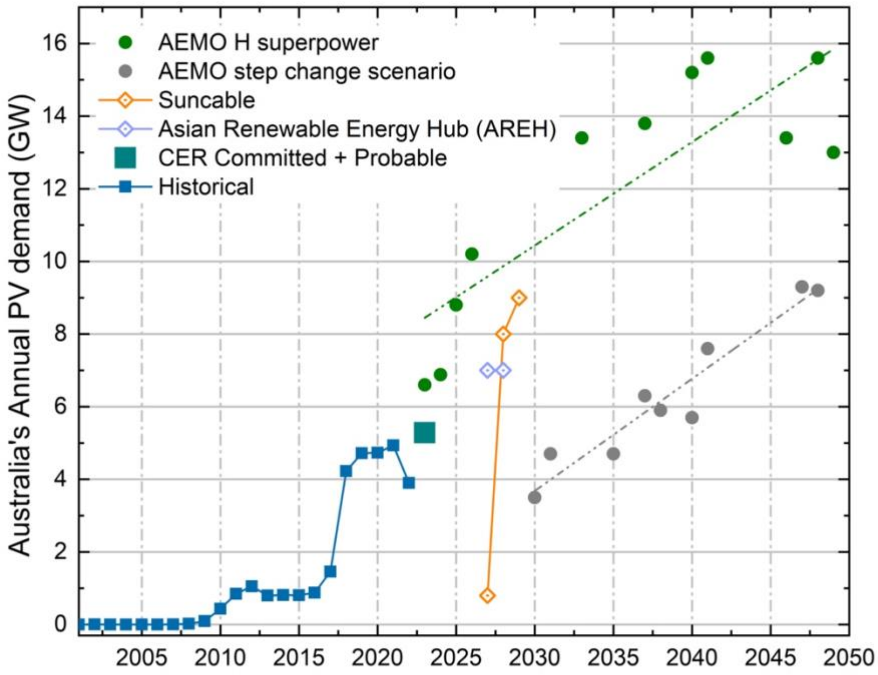

Figure 2-2: Australia's Solar PV annual demand forecast. Sources: AEC,[44] AEMO,[45] and APVI.[46]

As one example, the decarbonisation of Australia's current steel production via the hydrogen route and aluminium smelting could require 18 GW of PV.[47]However, a potential shift from Australia exporting approximately 880 million tonnes of iron ore to exporting green steel via the hydrogen route could require 430 GW of PV alone if PV is to provide half of the electricity required. Similarly, a shift to export green aluminium rather than bauxite/alumina could require approximately 53 GW of PV (with PV providing 50% of electricity demand)[48] To replace Australia's current energy requirements/exports through coal and gas, approximately 1.9 TW of PV would be required[49].

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[42] ARENA, 2023, https://arena.gov.au/knowledge-bank/the-incredible-ulcs/, viewed 2nd Nov 2023
[43] Net Zero Australia: Interim findings from a groundbreaking study (unimelb.edu.au)
[44] Australian Energy Council, "Solar Report", Q4 2022 and Q1 2023.
[45] AEMO, 2022 Integrated System Plan, June 2022.
[46] APVI, https://pv-map.apvi.org.au/analyses, viewed 5th April 2023.
[47] Assumes 880 Mt of iron ore can produce 540 Mt of green steel, with an electricity requirement of 3.5 MWh per tonne of steel based on numbers from https://rmi.org/wp-content/uploads/2019/09/green-steel-insight-brief.pdf and 14 MWh per tonne for aluminium smelting.
[48] Production values obtained from the US Geological Survey pubs.usgs.gov, 100 Mt of Bauxite can make 16.5Mt of Aluminium, 14 MWh per tonne - needs 231 TWh, i.e., 105 GW PV (at 100%).
[49] 360 million tonnes of coal per annum (FY 2020-2021) equating to 3,300 TWh of energy and 5,500 PJ from gas with electricity components assuming 40% efficiency.

Evidently, even the "Step Change Scenario" appears too cautious, as Australia has already exceeded the 5 GW per year installation target in the past, and large-scale private initiatives, such as the Sun Cable project and the Asian Renewable Energy Hub, which have significant PV capacity requirements, have not been factored in. Figure 2-2 shows the total targeted volumes of each of these projects as publicly announced, divided by a possible timeframe of installation. It is, therefore, more credible to expect between 10 GW and 15 GW additional solar capacity per annum from 2030 onwards. Nevertheless, even in AEMO's less ambitious "Step Change Scenario", the majority of power generation capacity in the National Electricity Market (NEM) will rely on solar power from distributed and utility-scale solar generators. This means, no matter which scenario unfolds, Australia will require a steady, reliable and affordable supply of solar modules to power its renewable energy future.

2.2. PV Supply across the Value Chain

2.2.1. Global Manufacturing Capacity

Chinese companies, such as LONGi, JinkoSolar, Trina Solar, JA Solar, Canadian Solar, Risen Energy, continue to lead the solar PV manufacturing industry with the largest production facilities in the world. Figure 2-3 illustrates the 2023 annual production output in GW for the major players across all segments of the market, together with the share of total global annual production.

A considerable number of these players have already embraced varying degrees of vertical integration, representing considerable investment, and are benefiting from economies of scale.

In the last decade, Chinese manufacturers have made remarkable strides in ingot and wafering expertise, and China is committed to protecting these advancements. Currently, the Chinese government is contemplating the implementation of export restrictions on manufacturing equipment for solar wafers, black silicon, and silicon casting. If these categories are included in the Chinese catalogue of restricted technology, manufacturers will be required to obtain technology export licenses from provincial departments in order to export these products[50].

[50] PV magazine, https://www.pv-magazine.com/2023/01/30/china-plans-to-introduce-restrictions-on-polysilicon-wafer-exports/ , 16th May 2023.

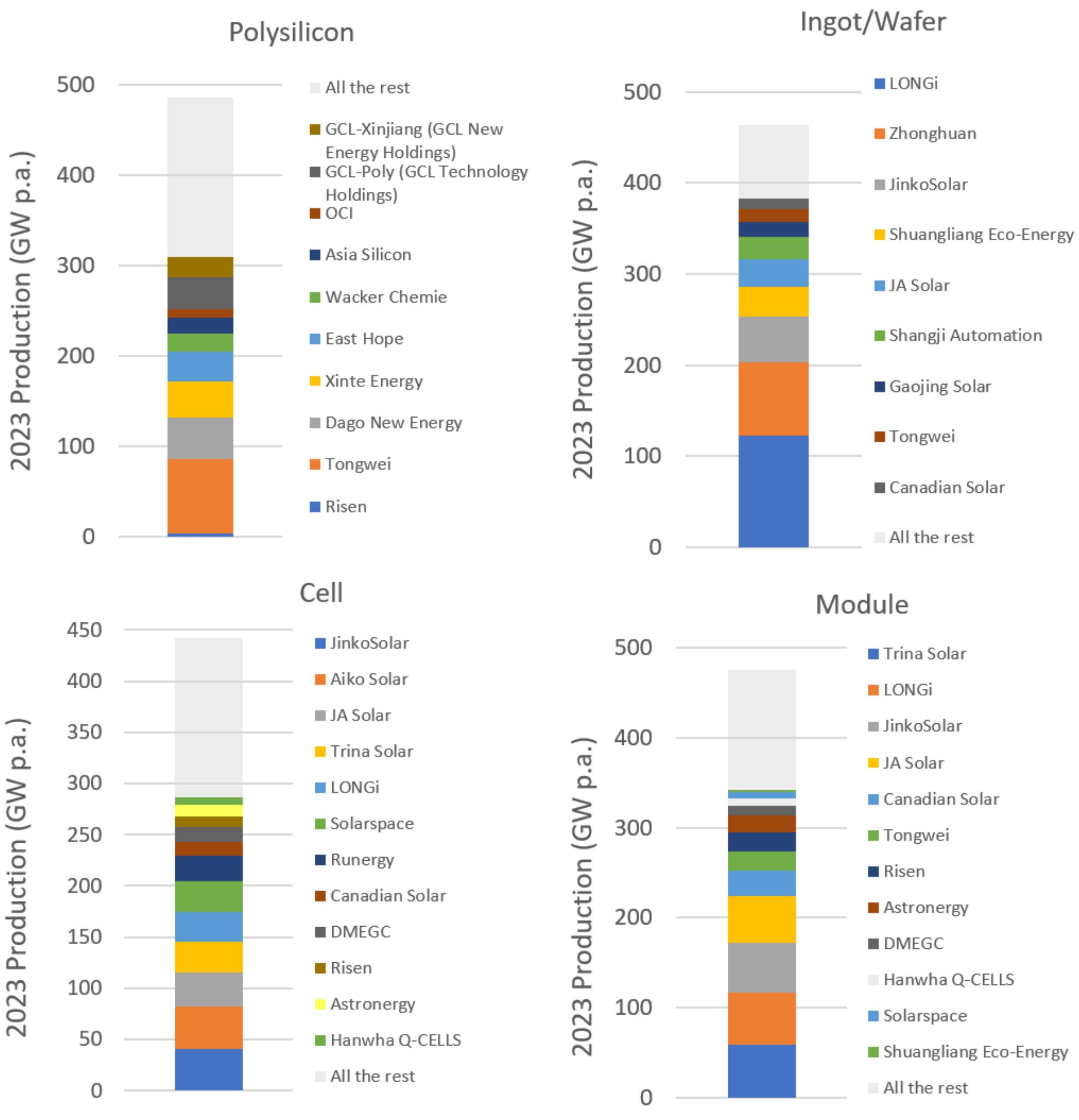

Figure 2-3: Top players per segment and corresponding annual production (GW p.a.) in 2023. Source: PV Cell Tech[51].

Polysilicon: As expected, the major changes in poly-Si capacity by the end of 2023 are concentrated in China. These expansions are financed with Chinese capital, constructed using Chinese equipment, and operated by Chinese-owned public/private entities. The domination of Chinese manufacturing of poly-Si in 2023 remains largely unchanged, with the only notable difference being a reduced proportion of production originating from Xinjiang.[52] At present, Germany's Wacker Chemie and South Korea's OCI are the only non-Chinese manufacturers with a relevant manufacturing capacity.

In 2023, there are some potential developments in poly-Si capacity outside China that may occur. Wacker's German operations may increase capacity[53], REC Silicon is planning to restart its FBR

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[51] PV Cell Tech, "PV Manufacturing & Technology Quarterly Report", April 2023.
[52] Ibid.
[53] PV magazine, https://www.pv-magazine.com/2022/05/27/wacker-to-expand-silicon-metal-production-in-norway/, viewed 5th May 2023.

production in the US[54], Hemlock might upgrade its US plant to increase shipments to the PV industry[55], and OCI may either transport legacy OCI poly-Si plant and equipment to Malaysia or revive its dormant capacity in Korea. As of October 2023, there have been no announcements of new poly-Si capacities as the result of IRA.

Ingots & wafers: In terms of ingots, the capacity in China is very large, resulting in a situation where very few plants typically operate at utilization rates exceeding 90%. When it comes to wafering, China currently dominates the market in every aspect. However, there are notable expansions taking place outside of China in 2023, primarily led by Chinese module suppliers targeting the US market. These companies, such as JA Solar, JinkoSolar, and Trina Solar, are establishing ingot/wafer capacity in Vietnam to facilitate customs clearance approval in the US. The three main wafer suppliers continue to be LONGi, GCL-SI, and Zhonghuan, which have a combined market share of around 50%. Currently, there are no non-Chinese players of relevant capacity in the ingot & wafer step. Incentivised by the passing of the IRA there have been a few announcements in the US to build ~30GW wafer capacity by approximately 2025[56], however approvals are still pending. [52]

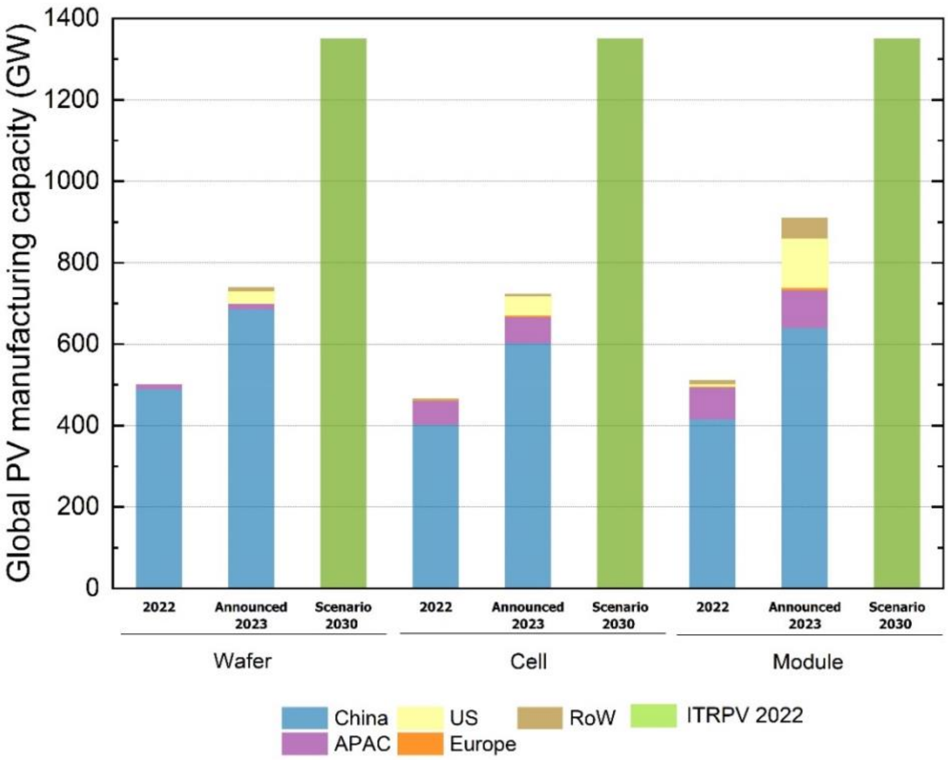

Figure 2-4: PV manufacturing capacity by country/region: current, announced in 2023 and required according to the ITRPV's broad electrification scenario. Source: PV Cell Tech[57] and US DOE.

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[54] PV Tech, https://www.pv-tech.org/rec-silicons-planned-moses-lake-reopening-underpinned-by-inflation-reduction-act-ceo-says/, viewed 5th May 2023.
[55] Ibid., 52.
[56] See e.g., https://www.pv-tech.org/hanwha-qcells-to-deepen-manufacturing-presence-in-georgia-with-solar-encapsulant-plant/ and https://cubicpv.com/cubicpv-announces-plans-to-build-silicon-wafer-facility-in-the-united-states/, viewed 5th Oct 2023.
[57] PV Cell Tech, "PV Manufacturing & Technology Quarterly Report", April 2023.

Cells: The cell production sector is also heavily dominated by Chinese companies such as Trina Solar, Aiko Solar, JA Solar, Jinko Solar, and LONGi, who collectively hold almost 60% of the market share. For 2023, it is projected that the top four module suppliers, namely LONGi, Trina, JA, and Jinko, will each surpass the 50 GW production mark, an accomplishment that is unlikely to be matched by any other players in the industry. Hanwha Q Cells, headquartered in South Korea, is the only non-Chinese player in this step of the silicon PV value chain with relevant manufacturing capacity. US company First Solar is the main player in the thin-film market segment with manufacturing facilities in the US, Malaysia, Vietnam and soon in India. However, its combined annual capacity by the end of 2023 will only reach around 12 GW. As of October 2023, announcements for cell production capacity in the US after IRA amount to a total of ~40GW with a target completion date set for 2024[58].

Modules: The domination of Chinese manufacturers is still strong in module manufacturing. However, as a result of the IRA, there has been an unprecedented appetite for module manufacture in the US that has led to over 100 GW of capacity announcements aimed for completion in 2024. An outstanding example comes from Hanwha Q Cells which has revealed plans for the largest investment to date in the US, involving the construction of a fully integrated plant with an annual capacity of approximately 3 GW[59]. In Europe, Enel has also announced new annual production capacity of 3 GW in Sicily[60]. However, these developments are relatively small compared to the bigger picture (Figure 2-4). Furthermore, and because of enduring substantial anti-dumping and countervailing tariffs when exporting to the US, Chinese solar cell and module manufacturers opted to shift their production facilities to Southeast Asian countries to access the US market. Nevertheless, the introduction of the IRA has now also enticed major Chinese producers like JA Solar and Jinko Solar to expand their manufacturing capacities inside the US[61].

2.2.2. Australian Manufacturing Capacity and Interest

The only current PV module manufacturer in Australia is Tindo Solar with an annual production capacity of approximately 160 MW,[62] although current annual production is only in the vicinity of 30 MW. With full utilisation of the production line, this represents only about 4% of the current demand for solar in Australia.

Nevertheless, during this study and following extensive engagement with stakeholders, there has been notable interest from parties across the PV value chain from those involved in poly-Si production to module manufacturing. Many of them are currently conducting their own feasibility studies to assess the potential for establishing manufacturing operations in Australia. Some of these prospectives include:

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[58] Basore, Paul, "Solar Photovoltaics Supply Chain in the United States", at PV Cell Tech conference Oct. 2023.
[59]PV magazine, https://www.pv-magazine.com/2023/04/18/us-inflation-reduction-act-triggers-plans-for-46-new-factories-says-industry-association/, viewed 5th May 2023.
[60]Enel, https://www.enel.com/media/explore/search-press-releases/press/2022/04/enel-green-power-signs-grant-agreement-with-the-eu-for-solar-panel-gigafactory-in-italy , viewed 1st May 2023.
[61] Solar Builders, https://solarbuildermag.com/news/module-manufacturing-moves-this-month-show-power-of-u-s-policy/, viewed 16th May 2023.
[62] Renew economy, https://reneweconomy.com.au/australias-only-solar-manufacturer-launches-11m-production-and-innovation-facility/ viewed 15th May 2023.

Quinbrook: a specialist investor, developer and operator of renewable energy and related energy transition assets with a focus on large scale solar across the US, UK and Australia. Quinbrook's operating and development pipeline of solar and solar + storage projects currently exceeds 20 GW of capacity with the recent addition of the Suncable project in the Northern Territory taking this to over 40 GW. Quinbrook is sponsoring the development of a large scale poly-Si plant in Australia to secure green poly-Si for its own needs and also for potential export. The poly-Si plant would be powered by renewables and remove other supply chain risks such as modern slavery. Quinbrook has commenced a process to select a qualified technology operator.

A new Australian company (which cannot be named yet due to the stage of the development): is planning to manufacture ingots and wafers in Australia leveraging excellent relationships with China for equipment and knowhow transfer. The company is also considering using their wafers for Australian modules via cell contract manufacturing overseas.

SunDrive: a solar commercialisation company based in Sydney, has developed cell technology that uses copper instead of silver for cell metallisation. Precursor cells are currently manufactured in China and metallised in Australia. A roadmap to 5 GW cell and module production has been presented[63].

Further upstream, the mg-Si production of Simcoa in WA is sufficient as an input for approximately 19 GW worth of annual poly-Si production for local solar, although it currently has other offtakers. Additionally, other players such as Fortescue Future Industries are also considering PV manufacturing, but using thin-film technology.[64]

Stakeholders have indicated that Australia is an attractive location for investment across every step of the value chain, if the right government support and long-term commitment to the solar manufacturing industry is provided. In addition to the value chain-specific comparative advantages highlighted in the sections above, Australia is well-known for its openness to trade and its low sovereign risk. Australia not only has good trade relationships with both the US and China, but also with the EU and Asian-Pacific countries, like Vietnam, Japan and Korea and is developing trade agreements with India. However, PV manufacturing in Australia also comes with challenges which are discussed in Section 4–'Barriers'.

2.3. Technology Options across the Value Chain for Viable, Relevant, and Timely Supply

There are several key interdependent considerations for the chosen technology to meet the three assessment principles of *timely, relevant,* and *viable.*

Timely: To reach 60 TW of cumulative installed capacity by 2050 globally, an average of 2 TW per year would need to be installed from now until 2050. However, with the industry currently deploying

[63] Renew Economy," https://reneweconomy.com.au/solar-innovator-sundrive-maps-out-plan-for-5gw-of-australian-pv-manufacturing/#:~:text=Sundrive%2C%20an%20Australian%20solar%20innovator,of%20solar%20PV%20a%20year.", viewed 24th Oct 2023.
[64] PV Magazine, https://www.pv-magazine.com/2022/05/05/fortescue-provides-backing-for-dutch-pv-module-maker/, viewed 28th July 2023.

around 300 GW per year, it will take 5-10 years to build up the global manufacturing capacity to TW scales of annual deployment. A realistic scenario is that in 2035-2040 there will be a couple of TW of capacity, and by 2050 the capacity could potentially reach ~4.5 TW per year in line with the ITRPV (see Section 2.1.1).

To have a reasonable chance of meeting the net-zero target by 2050, the immediate focus should be on technologies that are already produced at multi-GW scale, such that TW scales of annual manufacturing can be achieved by 2030. In addition, for the technology to be low cost and minimise emissions, PV systems must continue to operate for at least 25 years. The technology must also be capable of attracting financial backing ('bankable') with sufficient field data to ensure 25-year operation in the field can be achieved. These two aspects limit potential candidates in the short term to wafer-based silicon PV panels (PERC, TOPCon and SHJ)[65] and cadmium-telluride (CdTe) thin-film modules. Without any commercial products available on the market, recently developed tandem devices and thin-film perovskite variants are ruled out. This is in alignment with expectations from the ITRPV, whereby the expected market share for tandems in 2033 is <5%, with no expected market share for perovskites.

Relevant: The chosen technology must address the main solar power module market, which excludes niche products, and also have minimal challenges related to the availability of raw materials to allow TW scales of global annual manufacturing.

Viable: A viable technology requires consideration of both efficiency and cost. The efficiency must be reasonable to reduce balance of systems costs, which now make up an increasing portion of total PV costs. With current mainstream silicon PV modules at 21-23% efficiency, low-efficiency thin-film technologies (with the exception of First Solar CdTe modules at about 19%) can be ruled out for large-scale use, due to increasing balance of systems costs, driven by the need for more area related materials for balance of systems components (civils, wiring, labour etc).

In the case of CdTe, only one company (First Solar) produces the technology, and it is protected by a suite of patents. Hence, while it is possible for First Solar to set up manufacturing in Australia, within the S2S Study this technology was not assessed regarding the supply chain requirements due to the lack of publicly available and independently verifiable data.

The S2S Study focuses on wafer-based crystalline silicon technology (Table 1). Establishing a silicon-based solar industry will serve as a foundation for the development of advanced technologies not yet ready for mass production. This industry will create an ecosystem of suppliers, support services, skilled workers, and investment opportunities, enabling the growth of other solar technologies.

The study recognises the potential for incremental innovation within this established technology scope, such as copper contacting, bifacial technology, and glass-free technology. These innovations are considered within scope if they enhance existing investments in baseline facilities rather than

[65] PERC = Passivated Emitter and Rear Cell, TOPCon = Tunnel Oxide Passivated Contact, SHJ = Silicon Hetero-Junction

replacing them. The goal is to create a manufacturing platform that supports Australian innovations, including those already backed by government[66] R&D funding.

Table 1: PV technology comparison using S2S criteria. Sources for annual production capacity and prices. Sources: PV Cell Tech[67] and PV Insights[68].

	Timely	Relevant	Viable
Wafer-based silicon	✓ ~300 GW in 2022	✓ Can be TW scalable provided low silver consumption	✓ Mainstream technology in 2023 at US$0.20/W.
Cadmium telluride	✓ 9.1 GW in 2022	? Not scalable to TW scale due to tellurium scarcity	? Assessment out of reach to S2S. First Solar partnership needed for IP.
Thin-films (without First Solar CdTe)	? No significant market share	✓ Provided the use of abundant materials (e.g. thin film silicon)	? Higher efficiencies needed to reduce cost
Perovskites	? No commercial product available at scale	? Need to replace indium	? Need work on reliability/stability to ensure a bankable product with a 25-year lifetime
Tandem	? No commercial product available at scale	? Need to replace indium	? Need work on reliability/stability to ensure a bankable product with a 25-year lifetime
III-V materials	? Not in mass production	? GaAs limited by availability of gallium	? High cost of scarce materials and deposition technology

[66] For example the Australian Renewable Energy Agency supports the development of copper plating for the manufacturing of solar cells by Australian start-up SunDrive to drastically reduce the consumption of silver, https://arena.gov.au/projects/sundrive-copper-metallisation-demonstration/ viewed 29 May 2023
[67] PV Cell Tech, "PV Manufacturing & Technology Quarterly Report", April 2023.
[68] PV Insights, http://pvinsights.com/, viewed 15th May 2023.

3. Value Chain Assessment: A Deep Dive

In this Section an analysis of Australia's position with respect to China, which is the manufacturing market leader across the solar value chain, is given. A detailed Techno-Economic Analysis (TEA) of the solar value chain was carried out following an in-depth literature review, working with the industry contributors to this study, as well as several dozen stakeholders domestically and internationally.

The TEA helps to assess the key considerations that would allow Australia to build a viable solar manufacturing industry that is relevant in terms of size (GW-scale) and can be established in a timely manner to address the transition to renewable energy in the coming decade.

The cost analysis is based upon an in-depth understanding of the technologies and production metrics. Data inputs are sourced exclusively from reputable PV industry roadmaps, consultations with prominent manufacturers, and industry spot price references. Additionally, the analysis incorporates data acquired through collaborative engagement with poly-silicon producers, ingot and wafer suppliers, silicon solar cell manufacturers, module manufacturers, PV equipment suppliers, and consultants.

Considering the consultations with manufacturers operating at the market's highest volume, even though economies of scale have not been explicitly integrated into the analysis, it is assumed that the majority of the gathered input costs are applicable to manufacturers with substantial capacity and considerable purchasing power. Consequently, this analysis also proposes the minimum viable capacity necessary for Australia to meet such descriptive criteria and in doing so achieve global competitiveness within each step of the value chain.

The bottom-up cost analysis focuses on two primary scenarios: (a) the cost of production in China and (b) the cost of production in Australia using imported manufacturing equipment and materials. These scenarios are developed based on the assumptions outlined in Appendix A. Each section pertaining to a step in the value chain begins with a summary of key cost drivers, which are further consolidated and compared against the critical considerations of other steps in Section 4.

3.1. Poly-Si

Polysilicon (poly-Si) manufacturing is the conversion of commoditised metallurgical silicon (mg-Si) chunks (a few cm in diameter) with a purity of about 99% to high-purity poly-Si chunks (also some cm in diameter) with a purity of 99.9999% (6N) and higher. The manufacturing process consists of two distinct steps: (a) The metallurgical silicon is turned into trichlorosilane (TCS) gas, which is then purified, and (b) the TCS gas is deposited on to silicon seed rods using chemical vapour deposition as high-purity polysilicon, which is then broken up to poly-Si chunks. The manufacturing process is carried out in large chemical factories with significant land and energy requirements. Australia currently has neither the capabilities nor expertise to establish a poly-Si industry and partnering with overseas technology providers will be necessary.

The production costs of poly-Si at a large-scale chemical factory in China is estimated at 8.9 USD/kg including the source mg-Si material. The cost of manufacturing poly-Si in Australia is estimated to be 16 USD/kg assuming a facility of a minimum viable size of 25,000 t per annum. The manufacturing cost increase is mainly due to three factors:

i. **CAPEX/Depreciation:** Recent announcements for large poly-Si factories in China report capital costs of 1 – 1.2bn USD for a 100 kt per annum factory. Estimates for a factory in Australia are around 3 times higher, assuming the use of Chinese equipment and more if sourced from other countries. Reasons for higher capital costs include higher construction costs, shipping of equipment and installation staff from overseas, different technical, safety and environmental standards and longer project timelines.
ii. **Electricity:** The manufacturing costs of poly-Si are dominated by the cost of electricity. Whilst the exact electricity costs of Chinese poly-Si manufacturers are unknown, based on stakeholder consultation it is believed that 6 US c/kWh is common these days, whilst in the past costs were as low as 3.5 US c/kWh. Without any intervention, electricity costs in Australia delivered to site might be as high as 8 US c/kWh.
iii. **Mg-Si and import duties:** Whilst the majority of mg-Si is produced in China, the production of mg-Si is less concentrated in one region than the subsequent steps in the solar value chain. Australia currently has a mg-Si smelter with a capacity of 52,000 t, which is approximately double the value required to supply a 25,000 t/year Australian poly-Si factory, though offtake is in place for all current output. It is noted that the cheapest mg-Si comes from China. However, at this stage, metallurgical silicon imports from China are subject to a 55% import tariff, which increases the cost of the input material significantly - the tariff alone represents 9% of the cost of poly-Si production.

In the following sections of this chapter the details of the production requirements, material flow, utilities and land requirements, labour considerations, cost details and manufacturing in Australia will be discussed.

3.1.1. Poly-Si Manufacturing Technology

Purification of metallurgical grade silicon towards 6N or higher purity for solar-grade poly-Si is energy intensive. The mainstream method used to purify to metallurgical grade uses a modified Siemens chemical vapour deposition (CVD) method with heat and energy recovery, which yields an electricity requirement of 45 – 60 kWh/kg of polysilicon produced. While there are alternative technologies with lower electricity requirements, such as the fluidised bed reactor (FBR) technology (requiring approximately 20 kWh/kg), FBR is less mature and currently holds only a 5% market share, although it is anticipated to increase to about 20% by 2030[69]. Nevertheless, the benefits of reduced electricity consumption in FBR can be counteracted by increased unusable silicon and more structural impurities during ingot growth. Efforts to lower electricity costs and emissions will also erode the advantages of FBR compared to Siemens technology. Similarly, the use of upgraded metallurgical grade silicon may further reduce costs, but produce lower quality material, which is undesirable due to the industry's shift towards higher-efficiency panels, where the quality of bulk silicon material becomes increasingly important. Therefore, in this S2S Study, the primary focus is on poly-Si production using the Siemens route as shown in Figure 3-1.

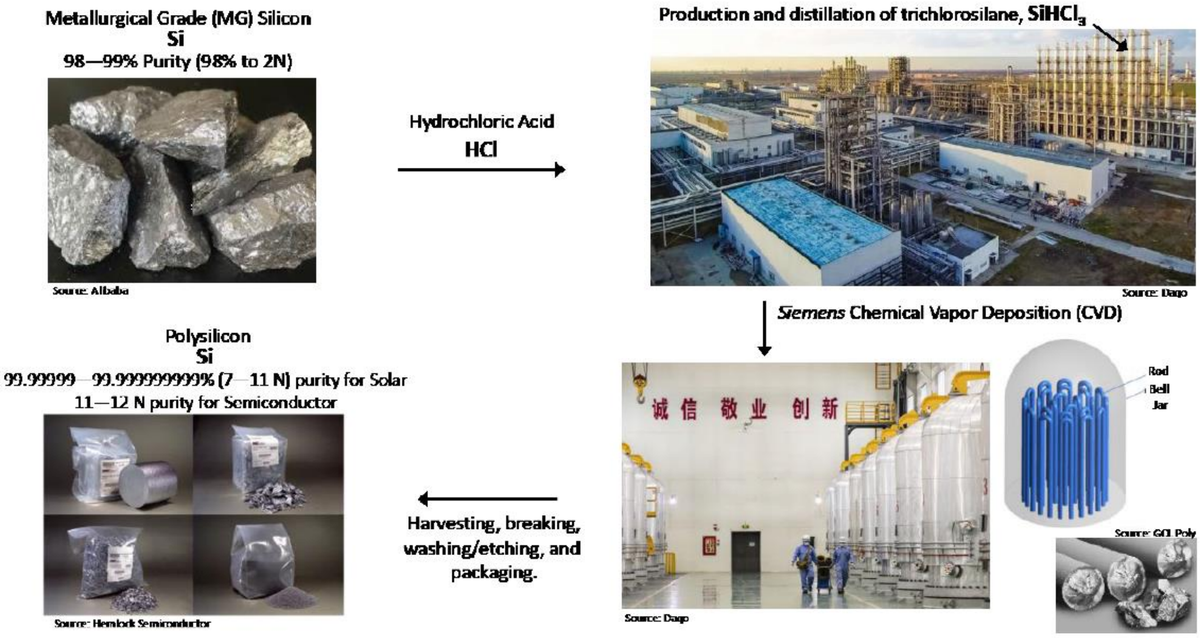

Figure 3-1: Steps for the purification of mg-Si to poly-Si using the Siemens chemical vapour deposition process, the gas purification and deposition processes are carried out at large chemical factories. Source: US DOE[70].

[69] VDMA, "International Technology Roadmap for Photovoltaic (ITRPV) – 2021 Results", Mar. 2022. , CPIA, "China PV Industry Development Roadmap", April 2023.
[70] US Department of Energy, "Solar Photovoltaics - Supply Chain Deep Dive Assessment", page 24, published 24th Feb. 2022

3.1.2. Production Requirements and Material Flows

At present, over 80% of the silicon purification from metallurgical grade (mg-Si[71], 2N - 4N purity) to solar grade (6N-11N purity) is carried out via the modified Siemens method, now a very mature technology following the production steps shown in

Figure 3-1. Historically this process was developed to serve the higher purity demands of the semiconductor industry, and it was mostly the off-grade silicon of this process that was used to serve the PV industry. However, with the enormous growth in PV demand of the last decade, over 80% of today's poly-Si production is dedicated to serving the PV industry[72] and over 90% is produced in China.

Poly-Si production demands substantial capital investment for plant construction. Additionally, highly skilled labour is essential for plant operations, and low electricity costs are imperative due to its energy-intensive nature. Poly-Si's energy requirements surpass those of ingot/wafering and cells by over 2.5x, and over 12x that of module production per GW production, making suitable geographical locations a challenge. At present, China dominates the industry, with manufacturing giants like Tongwei, Xinte, and Daqo adding capacities in excess of 100 kt per annum. Beyond China and now Mongolia, a few plant expansions and new builds have been announced, typically targeting manufacturing capacities of 10 – 40 kt per annum, some of which include vertically integrated plants. While the generous operational expenditure (OPEX) incentives provided by the US IRA have ignited interest in supply diversification in the US, the considerable capital expenditure (CAPEX) required poses challenges for expansions in this particular segment of the supply chain. Similarly, a CAPEX-only incentive through grants has also not been enough for some industry players as per stakeholder consultation.

The Siemens process, as shown in Figure 3-1 uses hydrochlorination of mg-Si to produce trichlorosilane (TCS, $SiHCl_3$), silicon tetrachloride (STC,$SiCl_4$) and hydrogen (H_2). Upon synthesis, a series of distillation cycles are carried out to purify the TCS further, which is subsequently fed, together with hydrogen, into a water-cooled-wall chemical vapour deposition (CVD) reactor. The gas decomposes onto the surface of 1150 °C heated and U-shaped high-purity silicon filaments[73] (7 - 9 mm wide), which thickens the filaments to 10-20 cm in diameter.

One key consideration for poly-Si production includes the co-location of TCS production with the silicon deposition reactor, with most CVD suppliers now offering TCS production solutions, given the ability to re-cycle several gases throughout the process.

The main input materials for poly-Si production include mg-Si, hydrochloric acid (HCl), sodium hydroxide (NaOH), and hydrogen (H_2)[74]. Due to the early stage of the production sequence, with subsequent steps in poly-Si purification and Czochralski (Cz) ingot growth, industrial grade HCl can be used, along with industrial grade NaOH for neutralising waste. Fortunately, Australia already produces

[71] Also known as silicon metal
[72] PV Cell Tech, "PV Manufacturing & Technology Quarterly Report", May 2023
[73] Also known as seed rods.
[74] Note: It is important to highlight that certain input gases, namely hydrogen gas, TCS, and HCl, are highly reactive and demand stringent safety protocols.

or has reliable suppliers for most of these materials such as Simcoa, Coogee Chemicals and BOC Gases. However, as per the defined minimum viable scale for a poly-Si plant, there will be an increased demand for these materials, requiring local suppliers to ramp up production.

For 'solar grade' mg-Si production (99.2-99.8%), high-purity silica sourced from quartz rock with low phosphorous content is needed, while silica sand of low iron content can be used for solar glass production.

While quartz deposits are geographically diverse, Australia has an abundance of quartz with suitable properties for solar silicon production[75], as well as existing metallurgical-grade silicon (mg-Si) production in Western Australia. Simcoa, a wholly owned subsidiary of Shin-Etsu Chemical Co, has current annual production of 52 kt per annum, and capacity to expand production for future domestic offtake in the silicon solar value chain. In addition, several companies have announced plans for potential mg-Si production in Queensland[76]. The mg-Si requirements for the minimum viable production size for poly-Si would use approximately 50% of Simcoa's current production levels if using locally produced mg-Si. Even though mg-Si is not the primary focus of this study, it is worth noting that global dominance in this area is also currently held by China[77]. Additional considerations for the requirements for mg-Si production, particularly related to sustainability with the use of carbon reductants are provided in Section 4.1.2.

Table 2: Annual input materials for poly-Si production and their consumption per GW of module manufacturing.

Material	Per GW	Per 10 GW
Metallurgical grade silicon (mg-Si)	2.75 kt	27.5 kt
Hydrochloric acid (HCl) (30%, industrial grade)	450 t	4.5 kt
Sodium hydroxide (NaOH) (industrial grade)	840 t	8.4 kt
Hydrogen (H_2)	120 t	1.2 kt
Hydrated lime ($Ca(OH)_2$)	375 t	3.75 kt
Si Filament	4 sets/t	
Graphite base	1.5 sets/t	
Graphite clamp	7 sets/t	

Note: Assuming 2.5 kt pa of poly-Si per GW production and a minimum viable scale of production of 25 kt per annum equivalent to 10 GW.

3.1.3. Utilities and Land

Polysilicon production is an electricity-intensive process. Each tonne of poly-Si requires in the vicinity of 50 MWh. This is roughly triple the electricity required by aluminium smelters per tonne of aluminium produced. Hence poly-Si production will require about 50% of the total electricity required

[75] CSIRO, https://www.csiro.au/en/research/natural-environment/critical-minerals/australian-silicon-action-plan, viewed 12 Aug., 2023.
[76] Taiyang News: https://taiyangnews.info/markets/silicon-solar-module-fab-in-australia/, viewed 14th Aug. 2023.
[77] US Geological Survey, Mineral Commodity Summaries, January 2023

across the poly-to-module supply chain per GW of modules produced. At a minimum viable capacity of 25 kt per annum, as will be described in Section 4.1.1, poly-Si production will require 1.5TWh per annum with approximately 170 MW average consumption. Although peak demand of each reactor may be up to 3x that of the average power, with 30-50 reactors required for this size facility, it is expected that with appropriate timing of individual reactors, the electrical demand will be relatively constant. The overall electricity demand will represent about 1.3% of the National Electricity Market (NEM) 2022-2023 demand (and ~ 0.8% of its total capacity) and about 14.5% of the South West Interconnected System (SWIS) demand (and ~10.5% of its total capacity). Table 3 shows the demand for land and utility services at a poly-Si facility and compares it to Australia's largest Aluminium smelter to put the scale into perspective.

Table 3: Annual utility and land requirements of poly-Si production per 1 GW and 10 GW of PV modules produced. Comparative case with Portland Aluminium smelter.

Input	Per GW	Per 10 GW	Portland Aluminium smelter (Vic) 300 kt/ annum
Electricity	130-150 GWh (17 MW avg.)	1.3-1.5 TWh 60.0 kWh / kg (170 MW avg. at highest range)	4.3 TWh 14.3 kWh / kg (490 MW avg.)
Cooling water	30,000 m^3	300,000 m^3	~600,000 m^3
Process heat (Natural gas, Steam, etc.)	15 GWh	150 GWh	-
Land requirements	~30,000 m^2	300,000 m^2	1,000,000 m^2

Note: Assuming 2.5 kt of poly-Si per GW pa.

3.1.4. Labour

Polysilicon production in Australia will require a highly specialised workforce, particularly skilled in chemical processing and production. Although this stage requires far less labour per GW produced compared to other PV manufacturing stages (~6% of all the supply chain per GW) the importance of expertise in chemical processes should not be overlooked. Fortunately, Australia possesses a wealth of chemical skill resources, stemming from various sectors. However, as the country strives to revitalise manufacturing and diversify supply chains, the increasing demand for skilled workers in hydrogen production and various other industries presents a challenge in sourcing the necessary labour for poly-Si production.

Table 4: Annual direct labour requirements for poly-Si production per 1 and 10 GW of module manufacturing.

Input	Per GW	Per 10 GW
Direct Labour* **	China: 35 FTE	350 FTE
Skills requirement	Chemical plant training	

*Note: Labour conditions in China and Australia differ in the number of hours worked by a full-time employee. In the cost analysis, it is assumed that 20% higher count may be required for a factory located in Australia. Similarly, it is assumed that additional non-direct labour would be employed for roles such as production management, quality control, engineering, R&D, sales, and administration.

3.1.5. Cost Analysis

As described in Appendix A, a bottom-up cost model has been built to estimate the cost of production for a China and Australia based Poly-Si factory as shown in Figure 3-2 and Figure 3-3.

Figure 3-4 shows the two scenarios broken down by cost category. The error bars shown for each cost component indicate the uncertainty range. The competitiveness of poly-Si manufacturing relies predominately on three factors: (i) electricity costs, (ii) capital expenditure; and (iii) procurement of mg-Si including import tariff considerations.

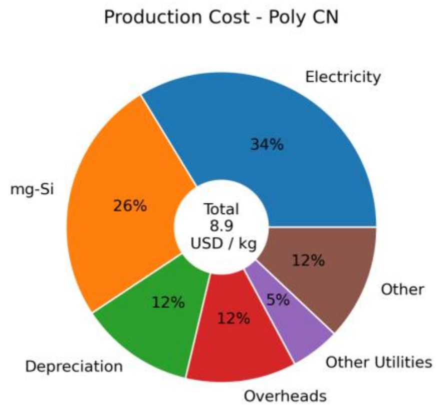

Figure 3-2: Poly-Si production costs in China

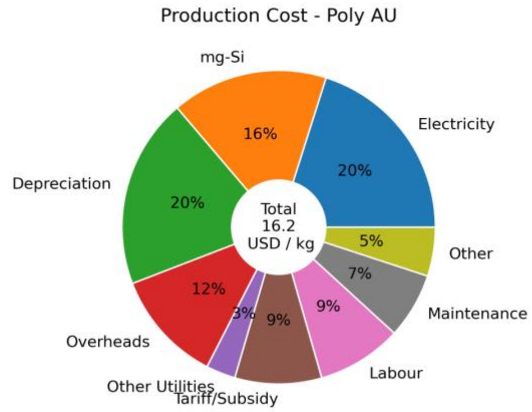

Figure 3-3: Poly-Si production costs in Australia

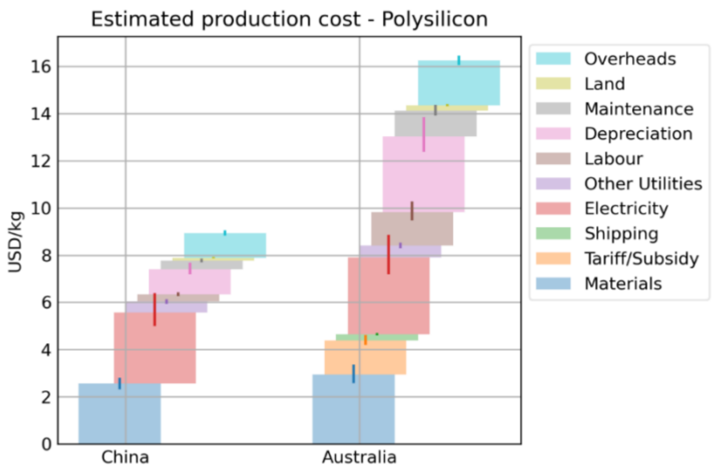

Figure 3-4: Comparison of poly-Si production costs in China and Australia

Comparing Australian based manufacturing with China based manufacturing, there are increased costs mainly due to the following factors:

- **Electricity** is the largest cost component, so poly-Si production is highly sensitive to the electricity price. The exact cost of electricity for different producers is unknown, with some sources suggesting historical costs as low as 3.5 USD c/kWh in some parts of China. However, higher prices around 6 USDc/kWh may be more common now. For Australia, the future expectations of electricity wholesale prices are between 4 and 12 USDc/kWh, with network charges of over 30% on top of that with high variability per state. In the TEA cost model, we assume a factory would prioritise sourcing lowest cost electricity, estimating a wholesale + network charge cost between 5 to 8 USDc/kWh. Therefore, access to low electricity prices is essential for cost competitiveness.

- **Capex (Depreciation in the cost model)** – Depreciation is the capex (initial investment cost) divided over the expected output of the factory over its lifetime. It is much higher in the Australian production case. Recent announcements for large poly-Si factories in China report capital costs of 1 – 1.2 bn USD or a 100 kt per annum factory. Estimates for a factory in Australia are around 3 times higher, even if assuming the use of imported low-cost Chinese equipment. Reasons for higher capital costs include higher construction costs, shipping of equipment and installation staff from overseas, different technical, safety and environmental standards and longer project timelines.
- **Metallurgical grade Si** (mg-Si) is the next highest cost component. In China, the cost of this input material is reported to be around USD 2/kg. For Australian production, if an Australian factory were to import this material from China, there is currently a 55% import tariff (Interim Dumping Duty and Interim Countervailing Duty), shown as "Tariff/Subsidy" costs in the figures. There is mg-Si made in Australia currently, although a 25kt/annum poly-Si factory would require approximately half of the entire production of Australian mg-Si capacity. Stakeholder consultation with existing and potential mg-Si producers indicated that expansion of mg-Si production capacity is possible to service a future domestic poly-Si market. However, the market price of mg-Si produced outside of China is much higher – around 4 USD/kg.

3.2. Ingot/Wafering

The ingot/wafering step in the value chain is the conversion of highly purified poly-Si chunks, a few centimetres in size, into Si wafers. This step consists of two parts: Firstly, the poly-Si chunks are melted and cylindrical monocrystalline silicon ingots over 200 mm in diameter and over 5 m in length are grown and pulled from the melt. Secondly, these ingots are cut into wafers with a thickness of 150-165 μm using diamond-wire saws. The wafers are then used for the subsequent solar cell manufacturing step. Both the input material of poly-Si chunks and the output material of Si wafers are easy to transport. Australia has neither the capabilities nor expertise at this stage to establish an ingot and wafer manufacturing base in Australia. Partnering with overseas technology providers will be necessary.

The conversion cost of the poly-Si to a wafer at a large-scale ingot/wafering plant in China is estimated at 0.025 USD/W excluding the cost of incoming poly-Si. The same conversion process at a plant in Australia is estimated to be 0.051 USD/W, assuming the plant has a minimum size of 1 GW or more. The additional costs for Australian manufacturing of 0.026 USD/W, are mainly due to three factors:

i. **Labour costs:** Whilst ongoing improvement in automation has reduced the share of labour costs in this value step, it is still a significant portion of the costs, with 100-200 full-time employees per GW depending on the level of automation. Due to the difference in labour costs between Australia and China, labour costs do play a significant role in this step and are the main contributor to the difference in conversion costs.
ii. **CAPEX/Depreciation:** China-based factories report investment costs of around 40M USD / GW for current state of the art toolsets, including automation and facility, and more if full turn-key lines are purchased with performance guarantees. The cost of Australian factories is likely to be around twice as high, for similar reasons as the poly-Si factories discussed previously.
iii. **Electricity:** The pulling of the monocrystalline ingot from the silicon melt requires significant amount of energy. Electricity prices in China are currently below Australia's. In order to close the cost gap, an Australian facility would need to have access to cheap, reliable energy from renewable energy sources, which is important to provide a low-carbon product for down-stream cell manufacturers.

In the following sections of this chapter, the details of the production requirements, material flow, utilities and land requirements, labour considerations, cost details and manufacturing in Australia will be discussed.

3.2.1. Ingot/wafer Manufacturing Technology

The dominant ingot technology is Czochralski (Cz) grown single crystalline silicon. P-type wafers are primarily gallium-doped, while emerging n-type wafers are phosphorus-doped. Ingot growers can relatively quickly change between producing n-type and p-type ingots, and therefore, can rapidly respond to specific wafer demands by industry. One alternative ingot technology is the float-zoning method. However, float-zoned silicon is too expensive for solar production. A second alternative is 'cast' and 'directionally-solidified' silicon. Although this material is cheaper to produce than a Cz ingot, the material is typically multi-crystalline, and on average, has a much lower quality than that from Cz ingots and is in the process of being phased out by the PV industry with the move to higher efficiency cell technologies.

Wafering is completely dominated by diamond wire sawing, with a substantially reduced cost and reduced kerf-loss[78] compared to previous sawing methods. Over the last decade Chinese companies have developed significant know-how with regard to equipment as well as manufacturing processes in the field of ingot and wafer manufacturing. China is now seeking to prohibit the export of technology used to produce M10 and G12 silicon wafers[79], which are in high demand.[50] This move will likely cement China's market leadership position while also slowing down the process of bringing the solar supply chain back onshore to regions such as Europe, India and the US, making this the most vulnerable step of the value chain. With complete market dominance by diamond wire sawing, the S2S Study thus focuses exclusively on diamond wire sawing and the silicon Cz grown process.

3.2.2. Production Requirements and Material Flows

Both the Czochralski ingot pulling and diamond wire sawing are well known technologies and the individual processing units are comparatively small. However, ingot and wafer manufacturing facilities are set-up at a multi-GW scale to leverage efficiencies from economies of scale and manufacturing excellence (See Figure 3-5).

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[78] The amount of silicon material wasted during the slicing process.

[79] Solar Power World; "The two new main wafer sizes that have dominated the market are the M10 (182-mm) and G12 (210-mm)", https://www.solarpowerworldonline.com/2023/01/downstream-players-adapt-to-irregular-panel-sizes-entering-all-markets/#:~:text=The%20two%20new%20main%20wafer,G12%20(210%2Dmm), viewed 22 May 2023

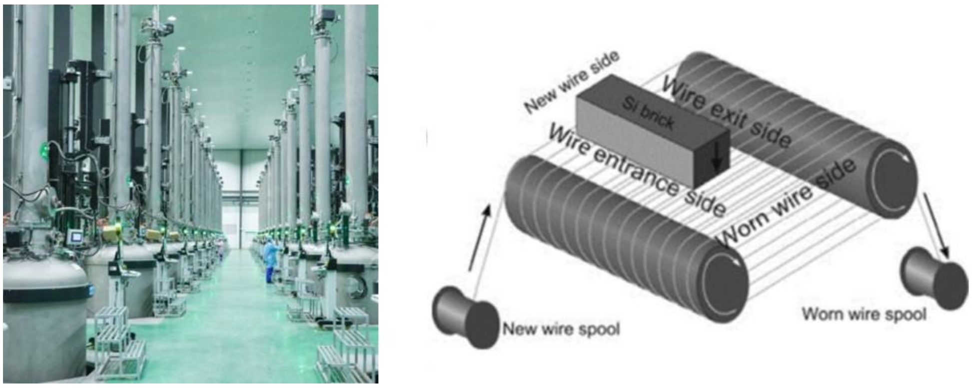

Figure 3-5: Ingot manufacturing facility (left)[80] and wafer sawing method (right)[81].

The Cz process is initiated by melting high-purity silicon chunks within a quartz crucible under an inert environment (e.g., argon gas). A seed crystal, attached to a rotating shaft, is introduced into the molten silicon and progressively drawn upwards. As the seed is lifted, it cools the silicon around it, forming a single, continuous crystal structure. The evolution of the continuous-Czochralski (CCz) method has resulted in the use of a single crucible for multiple ingot pulls, which were previously discarded after a single pull. For n-type wafers, magnetic Cz (MCz) is also used to reduce oxygen content by keeping most of the molten silicon away from the crucible walls. At present, technological advancements permit uninterrupted ingot pulls reaching over 5-6 pulls and up to 10 for select manufacturers. The number of ingot pulls is slightly more restricted for the phosphorous doped (n-type) technology compared to its gallium counterpart (p-type). This discrepancy arises from the significantly higher crystal quality requirement (lower metal content) for the n-type technology to reach equivalent or higher final cell efficiencies than p-type.

Based on the technology from the semiconductor industry, current production facilities grow ingots ranging in diameter from 200 mm, with lengths approximately 5.5 m (equivalent to 400–500 kg), to pilot-scale 300 mm diameter ingots exceeding 5 m in length (equivalent to 800 kg). With a mean growth rate of 1 mm per minute, the complete growth cycle requires approximately 4 days per ingot.

The resulting cylindrical ingot is squared and sliced into thin wafers, typically within a 150-165 µm thickness range. However, there is a marked trend toward further reduction of thicknesses to reduce cost, specifically evident in n-type technology where wafers in the range of 130-140 µm are already being mass produced. For the wafer cutting process, diamond-coated steel wires are typically used. These wires enwrap the ingot multiple times and simultaneously execute the cutting of all the wafers. A fraction of approximately one quarter of the ingot is lost as sawdust during the sawing process (referred to as kerf loss). There is still however some debate around the best wafer area for standardisation, with a wide range of silicon wafer sizes currently available in the market (e.g., 158.75 mm, 166 mm, 182 mm and 210 mm pseudo-square wafers). Nevertheless, top manufacturers have recently agreed on some module dimensions that would allow use of standardised rectangular wafer

[80] Jinko Solar, https://www.pv-magazine.com/2022/07/05/chinese-pv-industry-brief-jinkosolar-commissions-20-gw-n-type-ingot-fab-in-qinghai-province/, viewed 17 November 2023

[81] A. Bidiville, et al., "Effect of debris on the silicon wafering for solar cells", Sol. Energy Mater. Sol. Cells 95 (2011) 2490–2496, https://doi.org/10.1016/j.solmat.2011.04.038., viewed 17 November 2023

formats that should accommodate for small variations of the upcoming 300 mm diameter ingot[82]. A depiction of the standard ingot and wafering process is shown in Figure 3-6.

Key materials for the ingot and wafer manufacturing segment overlap with chemicals needed for the poly-Si and cell segments, such as NaOH, hydrofluoric acid (HF) and HCl in large quantities. However, for ingot processing, many chemicals require a high-purity or “semiconductor grade” level. There are some Australian chemical producers supplying several of the input materials, albeit at limited capacity, and it is unclear whether the purity of the chemicals produced are at the required level for ingot production and wafering. Additionally, deionised water and tap water is required for various processes throughout ingot/wafer production. The wafering process has, as the main input materials, the coolant or solvent and the diamond wire. The coolant is a particular mix of chemicals used to lubricate the sawing process and has been sold by several companies in China and the US.

Polysilicon is the main driver of the cost for this segment, and it is followed by crucibles. Even though the crucibles are made of silica, they require a very high-quality quartz to prevent impurities getting into the silicon melt during pulling at high temperatures. There is currently a limited supply of this quartz - mostly coming from the US - and given the escalating demand for the PV supply chain the cost per crucible can have significant variation and therefore impact final production costs. One common alternative from manufacturers is to use a combination of high quality (80%) and lower quality (20%) quartz for crucible production. Similarly, there is a continuous improvement in the number of pulls per crucible and length of ingot growth, which has dramatically reduced the number of crucibles per GW production. Although crucible recycling is a viable option, the resultant silica material lacks the requisite quality for integration into more crucible production. Typically, this material finds its way to the construction industry.

[82] Taiyang News, https://taiyangnews.info/technology/standardized-module-size-gets-unanimous-votes/, viewed 8th July 2023.

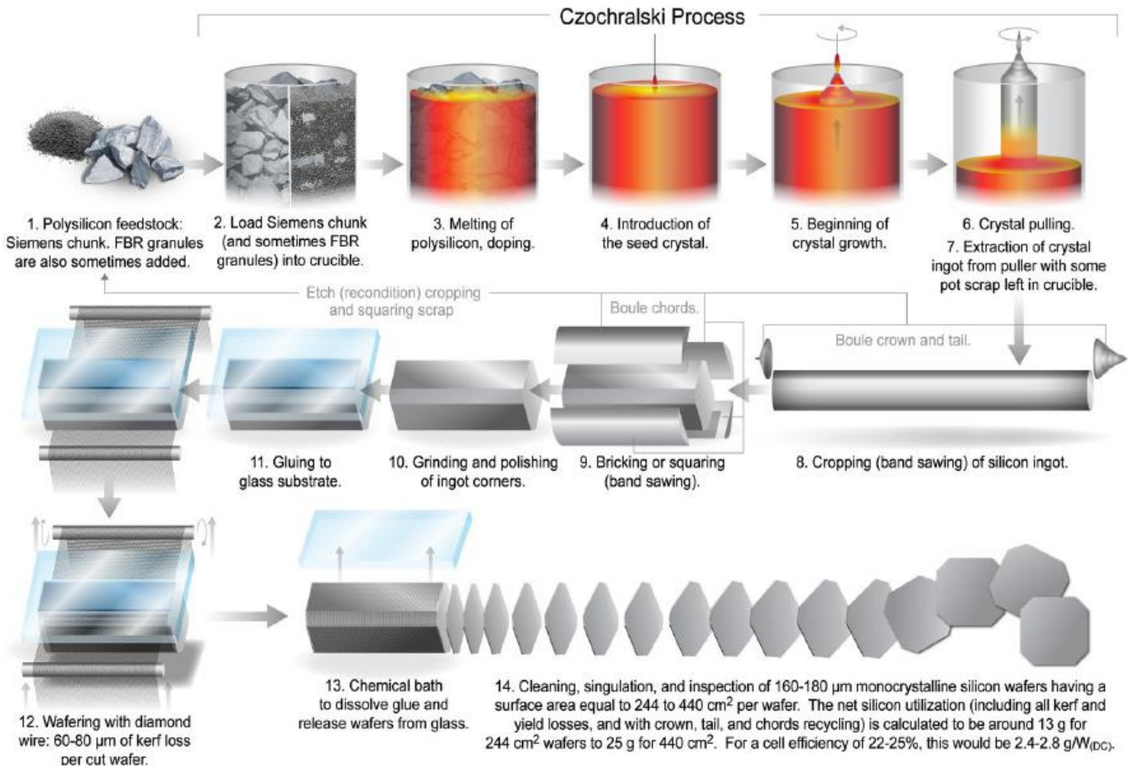

Figure 3-6: Process flow making mono-crystalline wafers. Source: US DOE[83]

With ongoing supply chain issues concerning crucibles, there could be an opportunity for Australia to explore its quartz deposits further. This assessment could determine if these deposits are suitable for crucible production and offer a solution to the current supply dominance held by a few US players.

Table 5: Annual input materials for ingot/wafer production and their consumption per GW of module manufacturing.

Materials	Requirement per GW
Polysilicon	2.5 kt
Hydrochloric acid (HCl)	13.5 t
Sodium hydroxide (NaOH)	175 t
Nitric acid (HNO_3)	160 t
Hydrofluoric acid (HF)	24 t
Hydrated lime ($Ca(OH)_2$)	50 t
Acetic acid (CH_3COOH)	195 t
$C_7H_{16}O_3$ (solvent)	1.5 kt
Alkylbenzene sulfonate (detergent)	1.2 kt
Acrylic binder	10 t
Argon	2.4 kt

[83] US Department of Energy, "Solar Photovoltaics - Supply Chain Deep Dive Assessment", page 30, published 24th Feb. 2022

Crucibles	< 800 (36 inch) – M10 and G12 compatible

3.2.3. Utilities and Land

Approximately 70% of the total electricity consumption within this segment is attributed to the ingot growth process, with the most automated lines requiring ~44 GWh/GW, requiring continuous cycles lasting 4 days. The subsequent steps, namely ingot squaring and slicing, account for an equal division of the remaining 30% of electricity consumption (~20 GWh/GW). Since the slicing process generates silicon particles, it involves substantial rinsing water usage, requiring subsequent treatment. To address this, Chinese manufacturers often engage waste management contractors to treat the rinse water.

Table 6: Annual utility and land requirements of ingot/wafer production per GW of module manufacturing

	Requirement per GW
Electricity	60-70 GWh (~5.7 - 8 MW)
Water for production	120,000 m^3
Land requirements	15,000 – 20,000 m^2

3.2.4. Labour

Ingot and wafer manufacturers offer a range of automation levels for equipment. Significant strides in automation, particularly within ingot pulling technology, have effectively reduced the number of operators. With the implementation of artificial intelligence for monitoring processes, one operator in a control room can control 64 (1 GW) ingot pullers for normal operations, or as much of 5 GW for new larger facilities. On the wafering side, advancements in technology have dramatically improved yield by the reduction of kerf losses, thereby reducing the required operator count per produced wafer. For the entire ingot/wafer production, some of the most highly automated lines require as low as 120 FTE of staffing per GW production.

Table 7: Annual direct labour requirements for ingot/wafer production per GW of module manufacturing.

	Requirement per GW
Direct Labour* **	China: 120 - 190 FTE
Skills requirement	Ingot: Chemical plant training Wafering: Machining training

*Note: Labour conditions in China and Australia differ in the number of hours worked by a full-time employee. In the cost analysis, it is assumed that 20% higher count may be required for a factory located in Australia. Similarly, it is assumed that additional non-direct labour would be employed for roles such as production management, quality control, engineering, R&D, sales, and administration.

3.2.5. Cost Analysis

A bottom-up cost model was built for a combined Ingot and wafer factory, since these processes are often combined. These cost analyses show only the production cost of Poly-Si into wafers and do not include the cost of the Poly-Si. Ingot/Wafer CN is an estimate of China-based production (Figure 3-7), and Ingot/Wafer AU is Australia-based production (Figure 3-8) where all input materials are imported from established supply chains in China.

A stacked bar graph for these two scenarios is shown in Figure 3-9. The cost difference is predominantly driven by differences in labour costs and depreciation (higher capital costs). Labour costs are substantially higher in Australia, dominating the total conversion cost for the AU scenario. Despite ongoing automation developments, labour is still a significant portion of the cost, even in China. The total labour cost difference between Australia and China is difficult to quantify. While data regarding average salaries in China and Australia can be obtained (typically 4 times higher in Australia), the exact difference will depend on the type of labour required (e.g., skilled, semi-skilled or non-skilled), the level of automation and relative productivity (including normal hours of work). It may be possible to optimise for Australian production by favouring higher CAPEX and lower labour alternatives options (i.e., more automation).

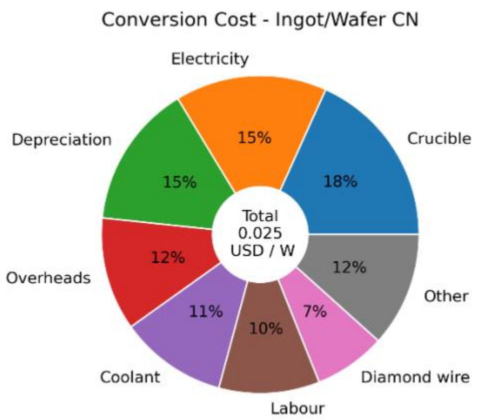

Figure 3-7: Ingot/ Wafer conversion costs in China

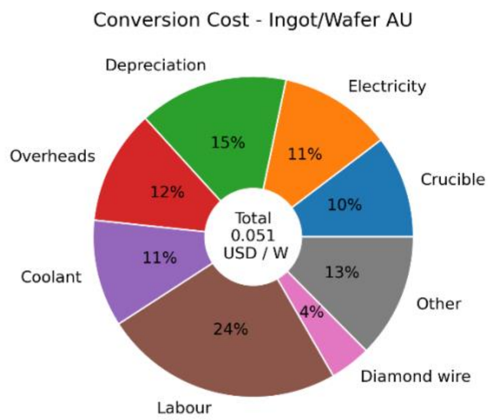

Figure 3-8: Ingot/ Wafer conversion costs in Australia

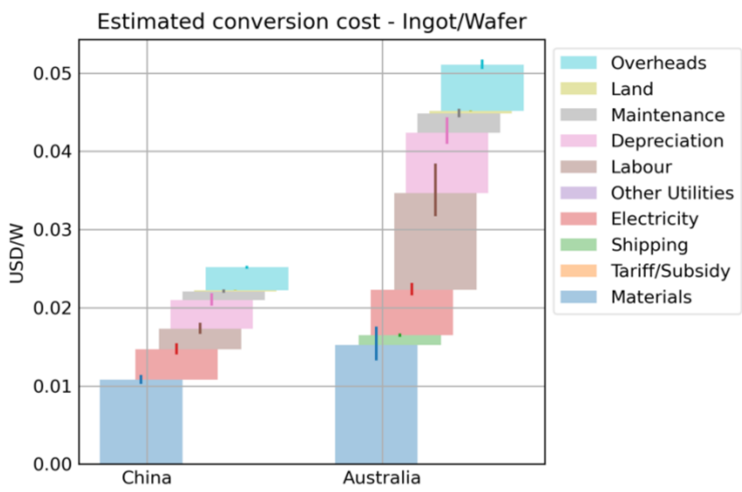

Figure 3-9: Comparison of ingot/wafer conversion costs in China and Australia

Depreciation of facility and equipment is also significant in this sector, with China-based factories reporting investment costs of around USD 25M / GW for current state of the art toolsets including automation. The production equipment of Australian factories is likely to be around twice as high, and the building/facility could be three times as high, for similar reasons to the Poly-Si factories.

Electricity is less important in this sector compared to Poly-Si production, but still significant. Access to low electricity prices will be important, but not as critical as in the poly-silicon sector. For this reason, electricity prices between 8 and 10 USD c/W are assumed, higher than for poly-silicon production.

The most significant input material (apart from the poly-Si itself) is the high purity quartz crucibles that are used to hold the molten silicon from which the ingot is pulled. As discussed above, these crucibles are made from very high purity quartz material, mostly sourced from the US, and are subject to significant price volatility.

3.3. Cell

The conversion process of the input wafer to a solar cell is a series of semiconductor processing steps. The process sequence used for the analysis in this report is the 'Tunnelling Oxide Passivated Contact' (TOPCon) technology introduced in 2013. Due to the rapidly increasing market share of this technology, it is predicted that it will be the dominating cell conversion technology for the coming decade.

The conversion cost of a wafer to a TOPCon solar cell is estimated at 0.034 USD/W at a large-scale solar cell factory in China. The conversion cost at a facility in Australia with a minimum viable size of 1 GW or more is estimated to be 0.068 USD/W roughly double that of China. The additional conversion cost of 0.034 USD/W, is mainly caused by three factors:

Labour: Over the last decade, Chinese factories have radically reduced labour requirements through automation. Depending on the level of automation a large-scale factory in China will require between 125-200 full-time employees. Due to the difference in labour costs between Australia and China, labour costs do play a significant role in this step and are the main contributor to the difference in conversion costs.

CAPEX/Depreciation: China-based factories reporting investment costs of around $25 M USD /GW for current state of the art toolsets including automation. The cost of Australian factories is likely to be around twice as high, for similar reasons as the poly-Si factories discussed previously, particularly if purchasing a turn-key line.

Material (Silver Paste): The silver paste used for electrical contact is the dominant material cost for cell manufacture. At present there is no supply of these materials in Australia, and the lowest cost pastes are produced in China. Australian companies with lower scale than their Chinese counterparts are likely to have to pay higher prices, and also lose the benefit of a Chinese subsidy on silver paste.

In the following sections of this chapter the details of the production requirements, material flow, utilities and land requirements, labour considerations, cost details and manufacturing in Australia will be discussed.

3.3.1. Cell Manufacturing Technology

Solar cells are manufactured in highly automated clean room facilities (see Figure 3-10). The typical scale of a solar cell manufacturing facility is now some 100 MWs to a several GWs.

Figure 3-10: Highly automated solar cell manufacturing line in a clean room facility.[84]

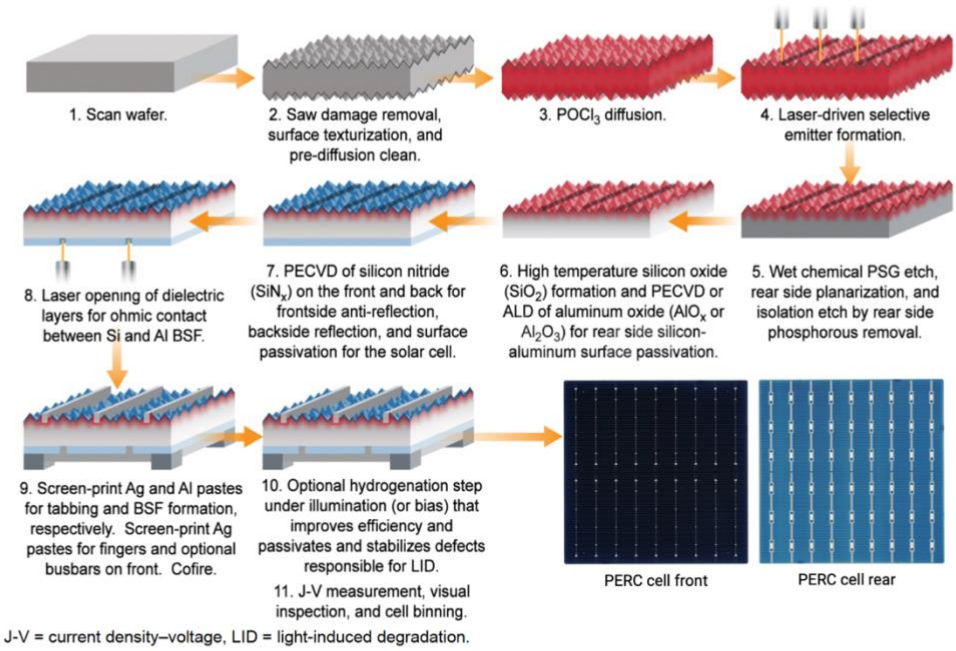

Figure 3-11: Process flow for manufacturing standard full-area PERC cells. Adapted from NREL.[85]

The current mainstream silicon solar cell technology is 'Passivated Emitter and Rear Cell' (PERC) technology, first developed at the University of New South Wales in the 1980s[86], with 80% market

[85] US National Renewable Energy Laboratory, "Photovoltaic (PV) Module Technologies: 2020 Benchmark Costs and Technology Evolution Framework Results", page 10, Published November 2021.
[86] Solar Power World, https://www.solarpowerworldonline.com/2016/07/what-is-perc-why-should-you-care/#:~:text=First%20developed%20in%20Australia%20in,side%20of%20a%20solar%20cell, viewed 15th May 2023

share. The process flow for manufacturing industrial PERC solar cells is shown in Figure 3-11. The expected efficiency limit for PERC solar cells in mass production is approximately 24.5%, which has already been demonstrated by Trina on large-area devices although module efficiencies remain in the 21.5 – 21.7% range due to losses during module assembly. Leading PERC producers use approximately 5 mg/W of silver (substantially lower than that reported in the ITRPV). This consumption level is suitable for TW scale PV production using 20% of global silver supply.

By 2026, the 'Tunnelling Oxide Passivated Contact' (TOPCon), another technology developed in Australia in the 80's[87], is expected to take over as the dominant technology with a higher efficiency potential for mass production, with cells in the range of 25 – 26% efficiency. TOPCon is largely seen as an upgrade from PERC with only a few additional tools required for a PERC line to be converted to TOPCon and using a very similar process flow. Therefore, TOPCon can benefit from the knowledge and equipment base for current mainstream PERC technology, reflected in its rapid adoption with over 4x capacity increase from 2022 to 2023[88]. At present TOPCon technology is also the highest performing mainstream commercial technology (with a module record efficiency of 22.65%[89]) with the lowest CAPEX, and highest throughput. More complex solar cell variants such as all-back-contact TOPCon have reached module efficiencies of 24%. Leading TOPCon producers use approximately 12 mg/W of silver. This consumption needs to reduce by approximately 60% to enable TW scale manufacturing[90], which will likely be achieved in the next 5 years using mainstream screen-printing technology or potentially other existing silver-free materials currently been explored at laboratory levels.

The third silicon-based technology is the silicon heterojunction (SHJ) technology which currently has ~9% of market share but expected to grow to over 25% within the next decade[91]. This technology has the potential to achieve higher performance (28.5% theoretical maximum) for which 26.8% has been already demonstrated at laboratory scale. At a module level however, they remain on par with TOPCon modules at 22.5%. Leading SHJ producers use approximately 20 mg/W of silver, the highest of all silicon solar cell technologies. This value needs to be reduced by 75% to enable TW scale manufacturing[92].

In the long-term, the SHJ technology could be an ideal stepping-stone towards the more advanced tandem technologies[93]. Nevertheless, its manufacture requires a completely different set of tools to current mainstream technology and will require further development to match current TOPCon costs per watt produced and long-term reliability. Current CAPEX for a SHJ line has about double the cost of

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[87] Green, M.A. and Blakers, A.W. (1983) 'Advantages of metal-insulator-semiconductor structures for silicon solar cells', Solar Cells, 8(1), pp. 3–16. Available at: https://doi.org/10.1016/0379-6787(83)90036-4.
[88] PV Cell Tech, "PV Manufacturing & Technology Quarterly Report", May 2023.
[89] Taiyang News, "Top solar modules 2022/H1 2023", https://taiyangnews.info/reports/top-solar-modules-h1-2023/ , 2023.
[90] Calculated assuming 12 tonnes per GW and using approximately 20% of the global silver supply according to the US Geological Survey, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-silver.pdf, viewed 19th Oct 2023.
[91] VDMA, "International Technology Roadmap for Photovoltaic (ITRPV) – 2022 Results", Apr. 2023.
[92] Calculated assuming 20 tonnes per GW and using approximately 20% of the global silver supply according to the US Geological Survey, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-silver.pdf, viewed 19th Oct 2023.
[93] Tandem solar cells have a higher efficiency potential than single junction solar cells by using multiple solar cells stacked on top of each other, more efficiently absorbing light from different parts of the spectrum. However, these solar cells have a CRI too low for consideration in this report.

a TOPCon line with the key drivers of cost being the productivity (tool throughput) and material costs, in particular from silver and indium[94].

From this analysis, the S2S Study has narrowed its focus to the state-of-the-art n-type TOPCon technology for the bottom-up cost analysis. This study will draw on the similarities to PERC and the more readily available information, based on its current market dominance.

3.3.2. Production Requirements and Material Flows

The TOPCon process largely follows the process sequence for established PERC production, meaning that the industry has largely benefited from the development and learnings of the PERC technology (See Figure 3-12). A number of techniques exist for the deposition/formation of poly-Si layers including plasma enhanced chemical vapor deposition (PECVD) and low-pressure chemical vapour deposition (LPCVD). A key difference for potential processing routes for TOPCon solar cell production is the choice of using either in-situ or ex-situ doping, requiring different toolsets. The ex-situ doping route requires a phosphorus tube diffusion (using phosphorous oxychloride ($POCl_3$)), similar to that for PERC, thereby capitalising on decades of experience in the industry with $POCl_3$ diffusions. In-situ doping requires a dopant gas (phosphine) during poly-Si[95] deposition, thereby avoiding the need for a subsequent diffusion. However, a high-temperature 'annealing' step is required to crystallise the poly-Si layer. It is worth noting that the choice between in-situ and ex-situ doping technology can impact both CAPEX and material requirements, with ex-situ doping offering a lower CAPEX option and less hazardous materials, while in-situ technology offers a more streamlined single tool processing solution but is yet to produce higher efficiency cells by thinning the poly-Si layer and thus reducing cost.

[94] Note: Besides the cost challenge, indium, silver and bismuth, are not abundant enough to make TW production sustainable at current consumption levels and thus demand further development.
[95] It is noted that the term poly-Si for cell production refers to poly-crystalline silicon, and not Poly-Si purification.

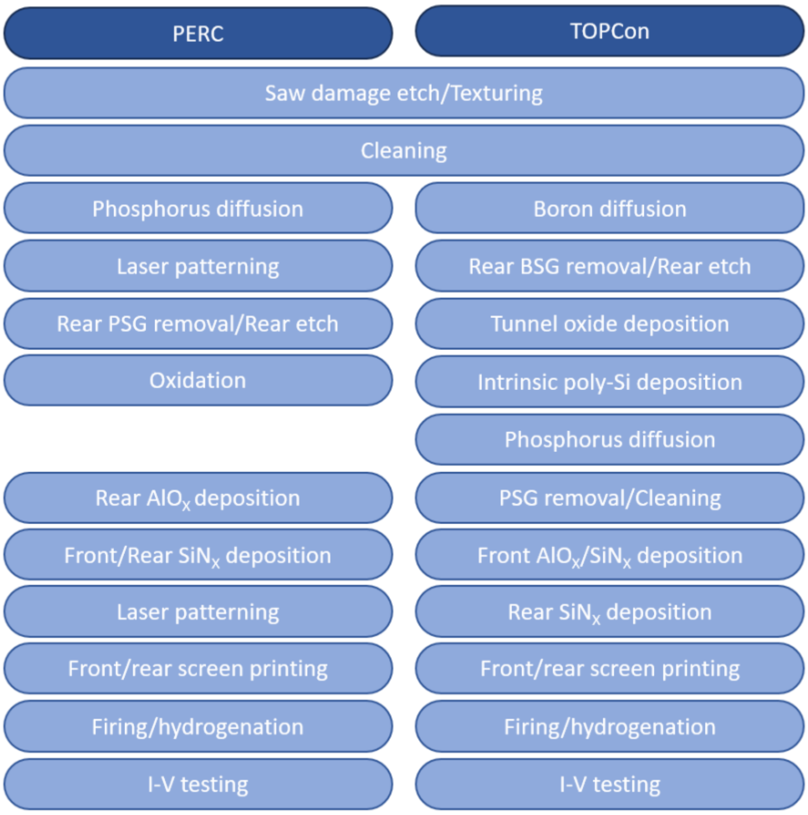

Figure 3-12: Process flow for typical industrial p-type PERC and n-type TOPCon solar cells.

In terms of characterisation equipment, several tools are required for quality-control and stability insurance. Some examples include, equipment for measuring sheet resistance, anti-reflection properties and passivation quality. In addition, nitrogen buffer stations for storing partially processed cells are also necessary to allow for equipment downtime.

A number of companies offer turnkey production line options for the fabrication of TOPCon solar cells as well as other mainstream technologies (i.e., PERC and SHJ). However, for TOPCon solar cells, the industry has not yet converged on a single process/flow equipment list. Turnkey production lines can be substantially more expensive than cherry-picking individual equipment. However, they also include options for the inline and offline characterisation equipment, training for staff, and performance guarantees, reducing the risks of market entry.

The exact materials and quantities required for TOPCon solar cell production will depend on the processing route and chosen toolset. Some indicative magnitudes for chemicals required in a TOPCon line is shown in Table 8. Similarly, for any other solar cell technology, differences in materials requirements can be expected.

Cell production requires a number of highly purified (semiconductor grade) chemicals and high purity (5N – 6N) gases. Some of the base chemicals and gases are already produced in Australia. However, for many chemicals, the quantity and purity will likely need to be improved to meet the strict requirements for cell processing. Without an established semiconductor industry, it is likely that major chemicals will need to be imported from overseas. For bulk gases, 5N purity can already be obtained from Australian suppliers. For some chemicals/gases such as silane (SiH_4), $POCL_3$, boron trichloride

(BCl_3), and trimethyl aluminium (TMA), quantities will be relatively small even at GW scale, and hence less likely to warrant interest from companies to establish production in Australia, rather than for other chemicals required in substantially higher quantities. Highly purified ‘deionised water’ is also required for many chemical processes and rinsing (~170 ML/GW). Fossil fuel gases such as methane have also been used for solar cell/module production in the past. However, a recent report from Trina suggests that fossil fuel gases have largely been eliminated from production.[96]

For many processes including boron diffusion, thermal oxidation, poly-Si deposition (for tube-based processes), and $POCl_3$ diffusion, high quality quartz tubes are required. Industry consultation suggests that the maintenance required for PECVD-based poly-Si with quartz tubes represents a challenge for manufacturing.

For the formation of metal contacts, metal screen printing pastes are required. A silver paste with a small amount of aluminium is used for the front surface contact, while a silver paste is used on the rear. These metal pastes, like all for the PV industry, are highly specialised and will require importation, at least initially. However, leading paste producers in China are exploring options to establish paste production outside of China. With metal pastes having such a large impact on cell production cost, there may be opportunities to encourage local paste production, particularly given Australia’s significant deposits of silver and aluminium, as well as other metals as the industry shifts to reduce the reliance on silver (e.g., replaced with copper). However, the quantities of silver pastes required are only in the range of 12 – 20 tonnes per year. Key solar cell metallisation paste companies include DuPont, Heraeus and Fusion.

Several chemicals and gases used for TOPCon production represent safety concerns and must be considered for approvals. Key chemicals of concern include HF and HCl. In addition, regardless of processing route, TOPCon requires the use of silane and TMA, which are dangerous gases.[97] If using in-situ doping, phosphine is also a safety concern that must be considered.[98]

Table 8: Annual input materials for TOPCon cell production and their consumption per GW of module manufacturing.

Materials	Requirement per GW per annum
Phosphorous oxychloride ($POCl_3$)	55 t or < 10 t phosphine (PH_3)
Boron trichloride (BCl_3)	20 t
Hydrochloric acid (HCl)	600 t
Hydrofluoric acid (HF)	1.7 t
Nitric acid (HNO_3)	500 t
Hydrogen peroxide (H_2O_2)	1.4 kt
Potassium hydroxide (KOH)	1.4 t

[96] Y. Chen at al. Progress in Photovoltaics Research and Applications. 2022; 1-11. doi:10.1002/pip.3626
[97] PERC also requires the use of silane and TMA.
[98] SHJ solar cell production requires dopant gases diborane and phosphine, and therefore need consideration for safety and approval implications.

Silver paste (combined front/rear)	12-20 t
Screens for screen printing	4,000 -8,000 units
Nitrous oxide (N_2O)	40 t
Silane (SiH_4)	50 t
Trimethylaluminium (TMA)	1 t
Ammonia (NH_3)	45 t
Nitrogen (N_2)	3.7 kt
Oxygen (O_2)	1 kt

3.3.3. Utilities and Land

For cell production, approximately 40 – 50 GWh of electricity is required per GW. It is noted that similar numbers (±10%) are required regardless of cell technology,[99] just depending on the processing route and toolset.

Factory footprint will also depend on the processing route and equipment toolset. An approximate footprint for a TOPCon factory and supporting facilities is 15,000 – 20,000 m^2 per GW. This is the highest of the three different cell technologies, due to the slightly higher number of processing steps compared to PERC. Utility and land requirements are provided in Table 9.

Table 9: Annual utility and land requirements of TOPCon cell production per GW of module manufacturing.

	Requirement per GW
Electricity	40-50 GWh (~5 MW)
Cooling water	0.2 m3/m2 (830 ML / GW)
DI water	40 kg/m2 (170 ML/GW)
Floor space	20,000 – 30,000m2

3.3.4. Labour

State-of-the-art TOPCon production lines are highly automated. It is estimated that for each GW of production, approximately 160 – 240 employees are required in China, depending on the level of automation. However, due to the shorter working hours in Australia, and lack of experience in running a cell production line, staffing requirements in Australia are estimated at 290 employees per GW. Over

[99] Chinese Photovoltaic Industry Association, "China PV Industry Development Roadmap 2022-2023".

time, it is expected that the number of staff per GW will reduce in Australia. Requirements and skills breakdown are summarised in Table 10.

Table 10: Annual direct labour requirements for TOPCon cell production per GW of module manufacturing.

	Requirement per GW
Direct Labour* **	China: 160-240 FTE
Skills requirement	Semiconductor manufacturing training

*Note: Labour conditions in China and Australia differ in the number of hours worked by a full-time employee. In the cost analysis, it is assumed that 20% higher count may be required for a factory located in Australia. Similarly, it is assumed that additional non-direct labour would be employed for roles such as production management, quality control, engineering, R&D, sales, and administration.

3.3.5. Cost Analysis

A bottom-up cost model was built to estimate the cost of Chinese (Figure 3-13) and Australian (Figure 3-14) based solar cell production. This estimate is the conversion cost of wafers to cells, so the cost of the incoming wafer is not included. The sources of cost difference between China and Australia are very similar to the Ingot/Wafer sector. Key differences include the higher cost of labour, capex/depreciation and higher material costs (primarily silver paste) as shown in Figure 3-15.

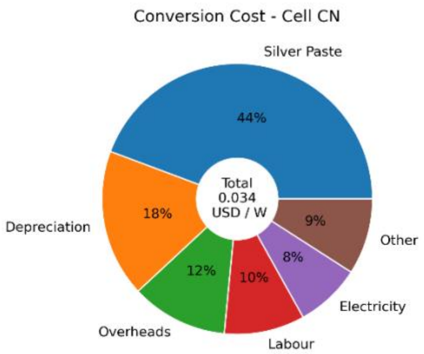

Figure 3-13: Cell conversion costs in China

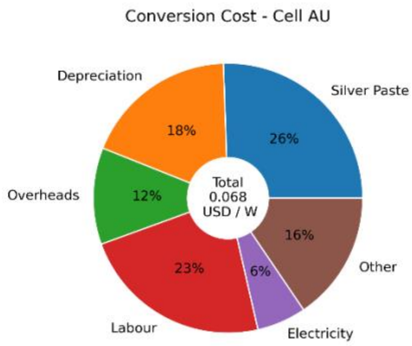

Figure 3-14: Cell conversion costs in Australia

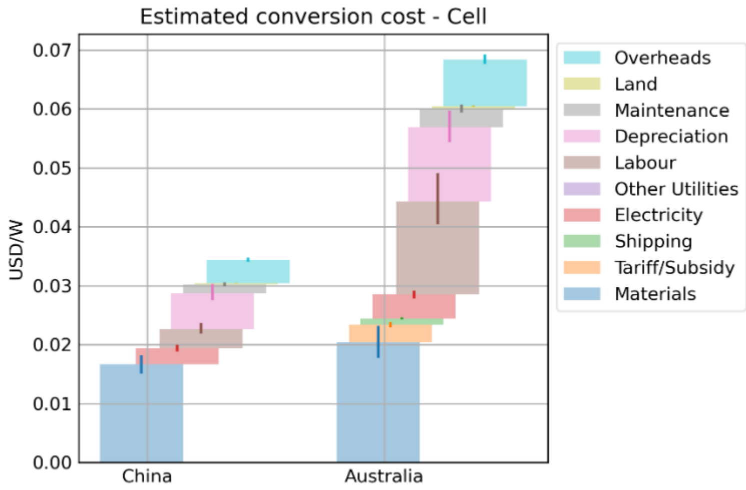

Figure 3-15: Comparison of cell conversion costs in China and Australia

Silver is the highest non-wafer cost for the fabrication of TOPCon solar cells. Chinese manufacturers benefit from a subsidy when using silver paste in China that is lost when exporting the paste to other countries (shown as Tariff/Subsidy in the graphs). When including this lost subsidy, silver paste for Australian manufacturers represents approximately 2 USD c/W of production cost or 30% of the conversion cost in Australia. The silver pastes are highly specialised and associated with significant IP for paste manufacturers. The potential for local manufacturing of silver pastes would require the interest of existing paste manufacturers to establish production in Australia. It is noted that some Chinese paste manufacturers are already exploring options for paste production outside of China in the South-East Asia region. Silver is subject to significant price fluctuations. With the growing demand for silver from the PV industry and shift to TOPCon, which requires more silver (t/GW) than current mainstream PERC, the demand for silver from the PV industry could create price volatility, negatively impacting the cost of solar cell production.

3.4. Modules

The assembly of solar cells into a solar module includes a series of distinct manufacturing steps. Initially the solar cells are interconnected to create strings using conductive ribbons. The strings of solar cells are then encapsulated between glass and back sheet or between two sheets of glass using encapsulating films and heated to around 200°C for 10-15 minutes. Finally, a junction box and aluminium frame are added to produce a solar module that will generate renewable energy for 25 years or more.

The conversion cost of solar cells to modules at a large-scale plant in China is estimated at 0.08 USD/W excluding the cost of the incoming solar cell. The same conversion cost at a plant in Australia is estimated to be 0.11 USD/W, assuming the plant has a minimum size of 1 GW or more. The additional costs of 0.03 USD/W, or 40% more than in China, are mainly due to three factors:

i. **Material costs:** The largest share of conversion costs are the additional materials that need to be procured for the module assembly process, including glass, aluminium frame, the encapsulant EVA, the interconnective ribbon, the backsheet and the junction box. Most of the material would be supplied by Chinese companies. The assumption made for the purpose of this analysis is that a 1 GW solar module factory in Australia will pay 10 – 20 % more (in addition to additional shipping costs) due to the fact that (a) the scale of 1 GW is moderate compared to the current Chinese module manufacturers, who operate facilities of several GWs, and (b) the procurement relationships between Chinese module companies and Chinese suppliers is stronger leading to lower costs.

ii. **Shipping:** Since most of the materials for module assembly will be imported from China or other places of origin to Australia additional shipment costs contribute to higher conversion costs.

iii. **Overhead Costs:** R&D (Research and Development) and SG&A (Sales, General and Administrative) costs are estimated to be higher in Australia due to the higher overall cost structure.

In the following sections of this chapter the details of the production requirements, material flow, utilities and land requirements, labour considerations, cost details and manufacturing in Australia will be discussed.

3.4.1. Module Manufacturing Technology

There are two dominant module constructions in the PV industry, namely monofacial and bifacial module technologies. However, both of these constructions are similar in that they use a glass sheet at the front of the module to protect the solar cells. Both module types also typically use bifacial and 'half-cut' cells because it is the most cost-effective technology at present. The module construction mainly differs in the use of materials at the rear, affecting the ability of the module to receive light from the rear of the panel.

Typically, monofacial module technologies use a white backsheet. These modules are typical for residential rooftop applications. To limit the panel weight to below 25 kg for ease of installation on rooftops, rooftop panels use a smaller format than utility-scale panels.

Modules for utility-scale PV are typically bifacial, with a glass-glass construction, increasing the total weight of the solar panel for a given power output, but increasing the yield per unit area. Without the same weight restrictions as for residential rooftop PV, utility-scale PV modules tend to be larger than residential rooftop panels. Figure 3-16 shows an image of the front and rear of mono-facial and bifacial PV modules.

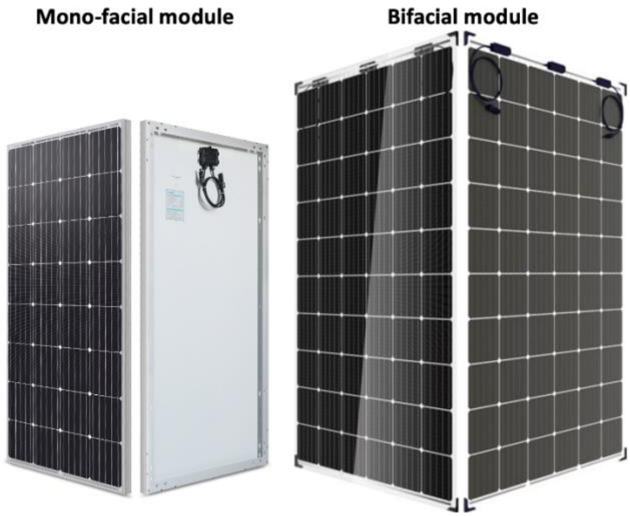

Figure 3-16: Front and rear of mono-facial (left)[100] and bifacial modules (right)[101].

An alternative 'glass free' module technology is a lightweight module technology by Sunman, reducing module weight by approximately 70%. However, with limited deployment to date, higher costs and a current annual production capacity of 1 GW,[102] the focus of the S2S Study is on mainstream glass PV module technology, with a view to adoption of other technologies over time.

[100] Renogy, https://www.bimobject.com/pt-br/renogy/product/renogy-rng-100d-100-watt-12-volt-monocrystalline-solar-panel, viewed 17th November 2023.
[101] Trina Solar, https://www.pveurope.eu/solar-modules/first-project-low-carbon-bifacial-dual-glass-modules-france, viewed 17th November 2023.
[102] PV Magazine, https://www.pv-magazine-australia.com/2022/01/13/sunman-opens-1gw-lightweight-pv-module-factory/, viewed 15th May 2023.

Due to the various wafer size options, a large number of potential module sizes and cell configurations exist. For simplicity and largest adoption in the market, in this study the focus will be on the monofacial module with 120 half-cut cells from 182 mm wafers which typically display a power output in the vicinity of 440 – 460 W.

In the past, module assembly was labour intensive, which gave countries with low labour costs a production cost advantage. Modern module assembly lines, however, are fully automated, which lends itself to economies of scale and facilities to manufacture 100 MWs to GWs of solar modules. An example of a highly automated module assembly line is shown in Figure 3-17.

Figure 3-17: Highly automated solar module assembly facility.[103]

3.4.2. Production Requirements and Material Flows

The prevailing method for manufacturing mono-facial solar modules can be simplified as follows: solar cells are interconnected using metallic ribbons in a series arrangement to create strings. Once these cell strings are formed, they are organised into an array and linked, again using metallic ribbons within a tabber and stringer machine. The subsequent stage involves encapsulation, wherein the cell arrays are placed over a glass sheet, and then layered between optically clear polymer-based sheets, including the extra layer of typically white polymer (back sheet) at the rear. This assembly is placed into a laminator and heated to around 200°C for 10-15 minutes. Subsequently, the junction box and frames are added to finalise the module. The process flow for manufacturing glass encapsulated PV modules in shown in Figure 3-18.

For a considerable period, the encapsulation step relied on ethylene-vinyl acetate (EVA) films for both front and rear sides. However, advancements in cell technology have heightened the importance of the encapsulant in ensuring module reliability, optimal performance and ultimately levelised cost of

[103] Trina Solar, https://vietnambiz.vn/tap-doan-trung-quoc-dinh-rot-400-trieu-usd-xay-nha-may-san-xuat-pin-nang-luong-mat-troi-tai-viet-nam-2023927161937751.htm, viewed 17th November 2023.

electricity. This has led to the adoption of more reliable but relatively more expensive films containing polyolefin elastomer (POE).

More generally, development in module assembly technology has focussed on cell interconnection, encapsulation, glass thickness (currently dominated by 3.2 mm and 2 mm), decreased usage of aluminium frames, and module size variations to serve specific markets. While the latter two factors contribute noticeably to reducing production costs, the first three factors play an increasingly critical role in ensuring reliability. Even more so with the current module warranty trend extending from 25 to 30 years. These three areas have also been increasingly influenced by solar cell technology. Inherent characteristics such as metallisation schemes, surface materials, and bifaciality significantly impact the module's long-term performance and, consequently, the overall cost of electricity. Just like the cell segment, module assembly equipment has a relatively shorter depreciation time, about 5 years, compared to the poly-Si and ingot/wafering steps, which have depreciation times of 10 and 7 years, respectively. This shorter depreciation is partly due to the fast-paced technological changes and the need to quickly adapt to material availability. For similar reasons, top Chinese solar panel manufacturers have their own accredited testing facilities that meet international standards. This allows them to internally certify modules when using a new bill-of-materials (BOM), ensuring a rapid path to market.

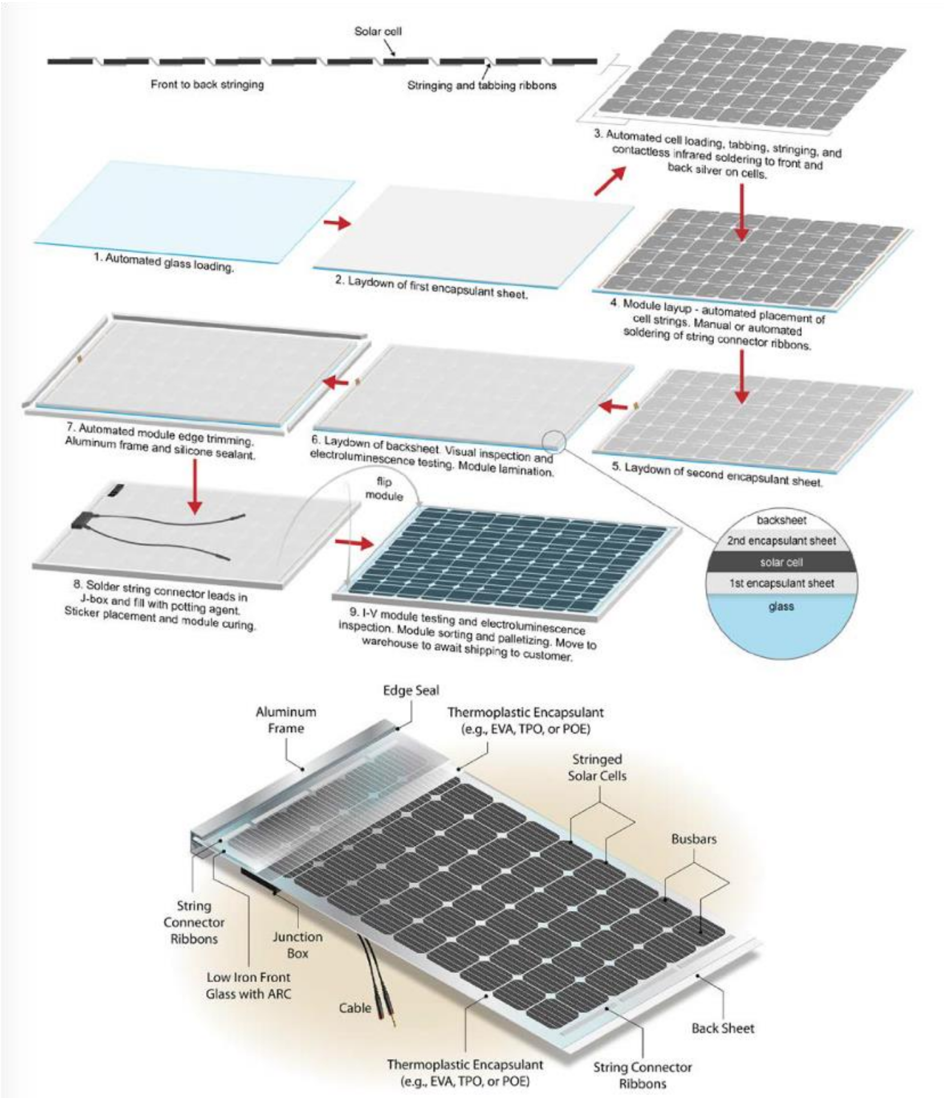

Figure 3-18: Process flow for a glass/backsheet solar module assembly. Source: NREL[104]

In terms of materials, apart from cells the primary contributors to the production cost of solar modules are the aluminium frames and the glass used in their assembly, collectively accounting for 40-50% of the total. Solar module assembly requires low-iron content and high-transmission flat glass. This glass is thermally or chemically tempered for durability and coated to be anti-reflective. For bifacial modules, it is possible to compromise light transmission by using lower-quality glass (typically soda-lime glass). Predominantly, standard modules continue to rely on 3.2mm thick low iron front glass (cover glass), representing a significant portion of the market (approximately 60%). Nonetheless, a growing number of manufacturers are adopting 2mm thick glass, primarily for application on both sides of bifacial glass-glass modules. Forecasts suggest the introduction of even thinner 1.6mm glasses, albeit in limited quantities within future production lines[105]. Unlike the high-quality quartz used for poly-Si production, solar glass requires silica sand for fabrication, for which Australia has large deposits. Nevertheless, at present, there is no available solar glass production in Australia.

[104] US National Renewable Energy Laboratory, “Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing: 1H 2018 Benchmark and Cost Reductions Roadmap”, page 32, published February 2019.
[105] Chinese Photovoltaic Industry Association (CPIA), “China PV Industry Development Roadmap 2022-2023”.

Furthermore, given the length of the production process, the minimum viable glass production capacities for float glass production would have to produce approximately 2 GW of cover glass per annum[106]. In contrast, aluminium extrusion is available in Australia through entities like Capral Limited, G. James, Alspec, and Ullrich Aluminium. However, their scale is not yet positioned for cost competitiveness.

Another key material for the module fabrication, as mentioned before, is the encapsulant film. There is a wide range of products available to serve different technologies and applications. The main differences reside in the mix of polymers used for each. Even though many of these materials use proprietary technology and China dominates the supply, multiple producers of these materials operate within the US and Europe. A summary of material requirements is shown in Table 11.

Table 11: Annual input materials and their consumption per GW of module manufacturing.

	Requirement per GW per annum[107]
Solar cells	1.8 kt
Aluminium	6 kt
Glass (coated, semi-tempered, low iron)	40 kt
Ethylene-vinyl acetate (EVA)	5 kt
Backsheet	2 kt (for mono-facial)
Polyolefin elastomer (POE)	2.5 kt (when used, halves EVA)
Silicone	800 t
Tin-coated copper ribbon	300 t
Busbars	65 t
Connector/Junction boxes	700 t

3.4.3. Utilities and Land

The requirements of a 1 GW solar module manufacturing line in term of land and utilities are listed in Table 12. Storage of the materials for module fabrication such as encapsulants require a temperature- and humidity-controlled room at 25 ± 2 °C.

[106] U.S Department of Energy, "Solar Photovoltaics, Supply Chain Deep Dive Assessment", Feb 2022.
[107] Assumption of a 2 m^2 solar module with a rated power 415W

Table 12: Annual utility and land requirements per GW of module manufacturing.

	Requirement per GW
Electricity	10-15 GWh (~1.5 MW avg.)
Floor space	10,000 - 20,000 m^2

3.4.4. Labour

Currently, the equipment used in component production lines primarily consists of welding machines, dicing machines, laminating machines, electrical characterisation tools (e.g., EL and IV testers[108]), framing machines, gluing machines, and loading and unloading robots. Most of these processes operate with a high degree of automation, with personnel primarily focusing on quality monitoring steps and overseeing the stringer tools—a critical area often susceptible to fault issues. A summary of labour requirements is shown in Table 13.

Table 13: Annual direct labour requirements per GW of module manufacturing.

	Requirement per GW
Direct Labour*,**	China: 170 - 260 FTE
Skills requirement	Mechanical assembly and reliability testing training

* Note: Labour conditions in China and Australia also differ in the number of hours worked by a full-time employee. In the cost analysis, it is assumed that 20% higher count may be required for a factory located in Australia.

** Note that additional non-direct labour would be employed in a factory for roles such as production management, quality control, engineering, R&D, sales, and administration.

3.4.5. Cost Analysis

A bottom-up cost model was built as described in Appendix A. Figure 3-19 (China) and Figure 3-20 (Australia) show the cost breakdown of the conversion cost for mono-facial module fabrication excluding the cost of the cells.

[108] EL - Electroluminescence, IV - current-voltage

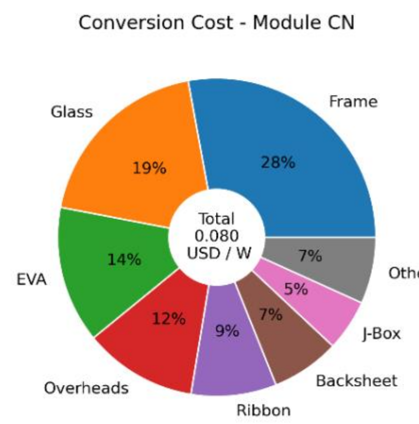

Figure 3-19: Module conversion costs in China. Note: labour costs have been included inside 'other'.

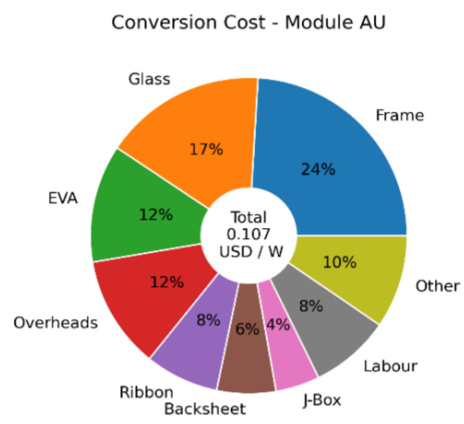

Figure 3-20: Module conversion costs in Australia.

The direct comparison of the module conversion costs between a Chinese and Australian facility is shown in Figure 3-21. The costs in this sector are dominated by materials. As noted in Appendix A, there is an assumption that an Australian module factory would need to pay 10 - 20% higher prices for these materials due to smaller production capacity and so reduced purchasing power. In addition to this, international shipping costs are estimated. Currently there are no import tariffs expected for the input materials.

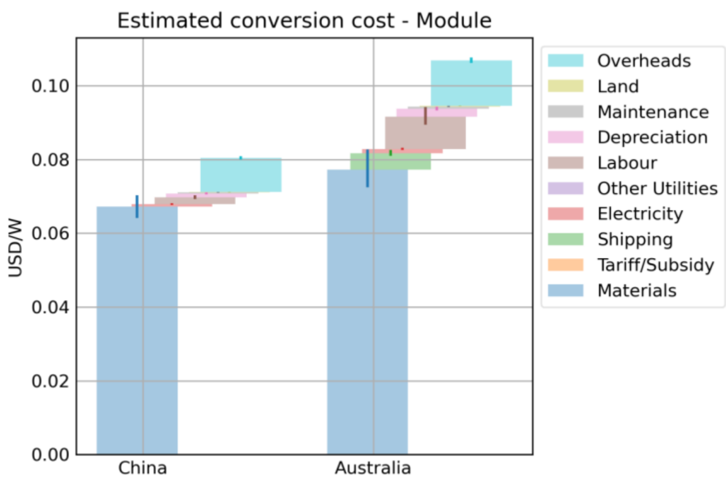

Figure 3-21: Comparison of module conversion costs in China and in Australia

The two dominant material costs are the aluminium frame and the glass. Aluminium is produced in Australia, so there is the potential to produce modules using Australian product, although due to higher labour and energy costs in Australia and lower production volumes (reduced economies of scale), the cost would likely be significantly higher, at least in the short term.

In the past, low-iron glass suitable for solar modules was produced in Australia, but that facility is no longer operating. The production of low-iron solar glass in Australia would require significant investment, but could provide the benefit of reduced shipping distance and cost from China of this very heavy (high shipping cost) input material.

3.5. Summary

Based on the techno-economic cost analysis, the combined differential between cost of production in China and Australia across the value chain amounts to approximately USD 0.11/W as summarised in Figure 3-22 which would require support of approximately AUD 110 million/GW produced. Further translated to the impact on cost of energy, this equates to approximately AUD 0.0024/kWh produced.[109] However, if Australia were only to develop manufacturing capability at targeted steps of the value chain and import the outputs of previous steps from China, or develop partnerships with third-country manufacturers, the cost differential could be lower, though self-reliance would of course remain lower.

The key considerations for each step in the value chain are not identical, and are summarised as follows:

- **Poly-Si conversion** is dominated by both the initial capital expenditure (CAPEX), since the process is a large-scale chemical process, and the cost of electricity, because the manufacturing process is highly energy-intensive. In addition, access to low-cost mg-Si as input material is a key driver for a viable poly-Si industry.
- **Ingot / wafering conversion** is dominated by labour costs, despite the fact that Chinese manufacturers have made significant progress in automation. This means that any facility in Australia needs to have the highest level of automation and manufacturing excellence in order to be viable. In addition to labour costs, CAPEX and electricity costs also play an important role in this step.
- **Cell conversion** is also dominated by labour costs and CAPEX. There is also a need to source competitively priced materials, in particular the expensive silver paste.
- **Module conversion** is dominated by the material and shipping costs since the value-add of the manufacturing process is moderate compared to the cost of the input materials.

The TEA showed that each step in the solar value chain will have higher fundamental manufacturing cost for a manufacturing facility in Australia compared a large-scale facility in China. Figure 3-22 shows the total manufacturing costs in Australia and China when poly-Si is produced, and then converted to ingot/wafer, cell and modules. This assumes hypothetical manufacturing facilities of minimum viable scale in Australia importing all materials from existing supply chains in China. However, it is important to keep in mind that the rapid reduction in manufacturing costs in China continues to be greatly related to the vast support given by the Chinese government who set the solar PV industry as national strategic industry over two decades ago.

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[109] Assuming 2200 kWh/kWp per year, 25 years of operation with derating to 87%

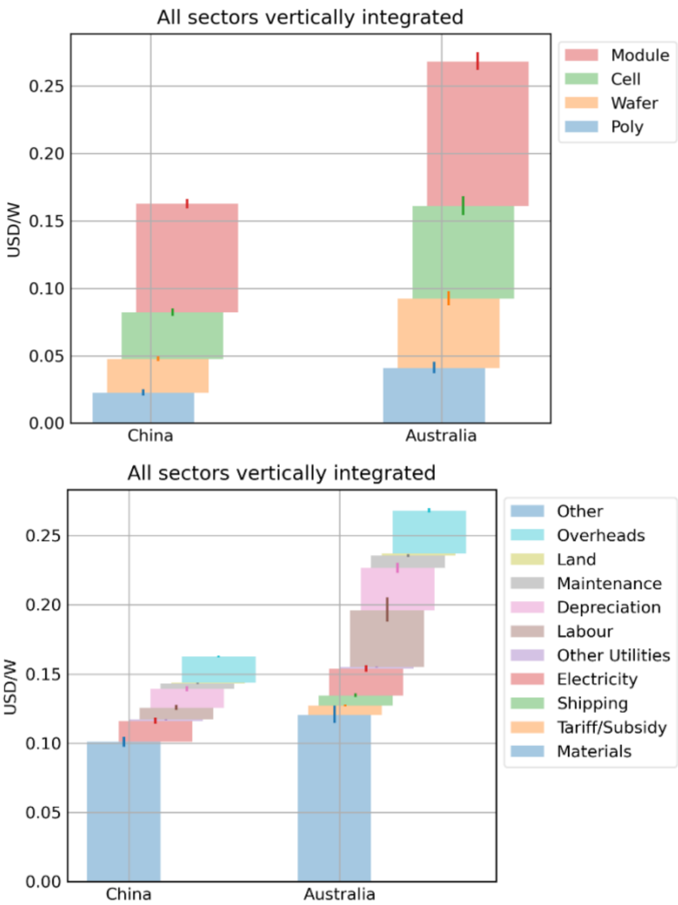

Figure 3-22: Cumulative conversion costs from poly-Si to solar module across the value chain and by key inputs, comparing the costs at manufacturing facilities in Australia (AU) versus in China (CN) in USD/W.

The differential costs of each conversion step in the value chain are shown in Figure 3-23. The additional costs across the value chain vary from 19% to 104%. Considering this cost disadvantage, Australia would not be in the position to build a *viable*, *relevant* and *timely* solar manufacturing industry across any of the steps in the value chain, unless active support is provided through policy interventions in the short term. Industry policies will be required to build out a viable solar industry in Australia of relevant scale. This industry will need to be powered by low-cost renewable energy of which Australia will have abundance in the future, and it will benefit from the ambitions to re-establish manufacturing in Australia.

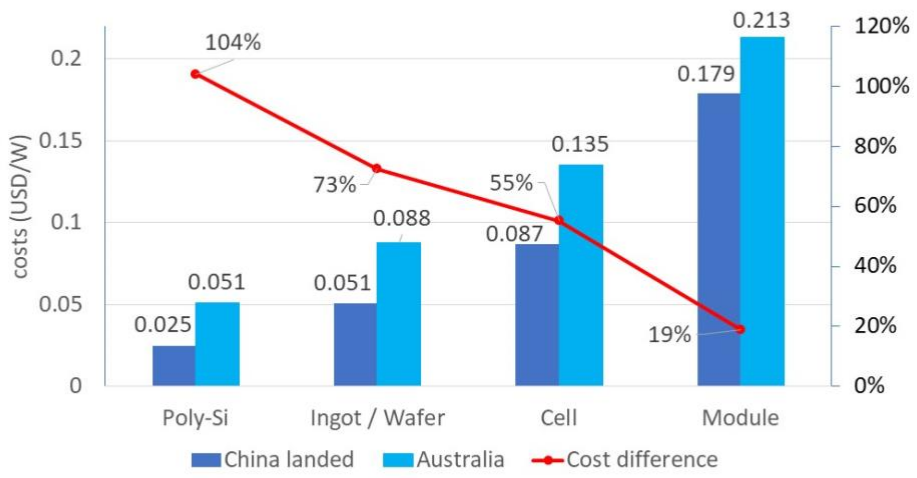

Figure 3-23: Comparison of landed good costs from China in Australia vs cost of production in Australia using input materials from China across the value chain. This chart assumes large volume procurement and includes shipping costs.

For Australian PV manufacturing, evaluating facility scale and key characteristics at each value chain stage informs the potential short- to long-term market establishment opportunities, and opportunities to leverage natural competitive advantages. These characteristics also impact location considerations across the value chain, discussed in Section 4.5. A comparison of select characteristics is presented in Figure 3-24.

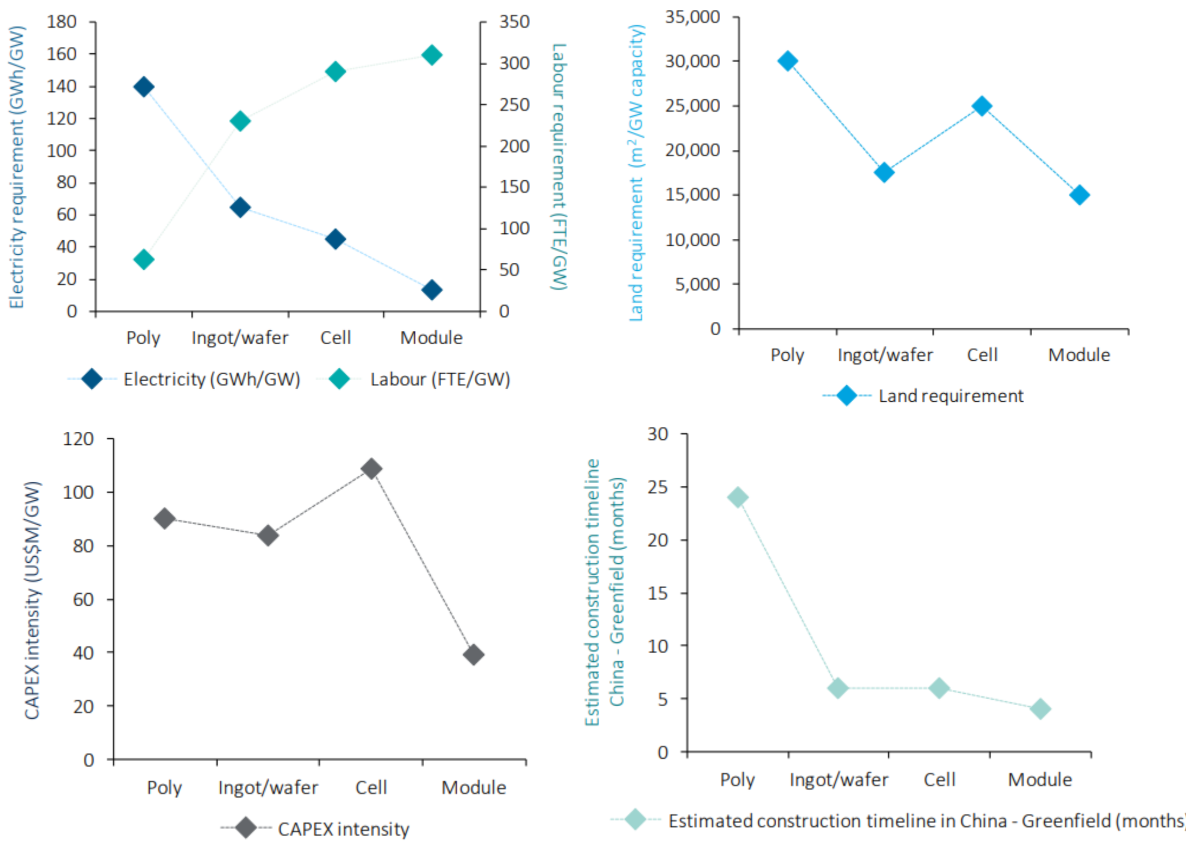

Figure 3-24: Key differentiating manufacturing requirements across the PV value chain in Australia, with the exception of estimated construction time which is for China.

4. Manufacturing in Australia

When it comes to establishing a diversified solar PV supply chain, Australia needs to firstly assess the value of reducing sovereign risk across the solar value chain and the increase of geo-political stability that comes from a higher level of energy independence. Secondly, Australia needs to consider its competitive advantage on a global stage, and how this compares to and complements alternative solar PV onshoring efforts such as in India, Europe and the United States. By doing so Australia will need to clearly consider where it differentiates itself from these major economies, and where it can play a complementary role, to attract investment and knowledge that may otherwise be pulled to other markets.

Stakeholders indicated that Australia is an attractive location for investment across every step of the value chain, if the right government support and long-term commitment to the solar manufacturing industry is provided. In addition to the value chain-specific comparative advantages highlighted in the sections below, Australia is well-known for its openness to trade and its low sovereign risk. Australia not only has good trade relationships with both the US and China, but also with the EU, India and Asia-Pacific countries like Vietnam, Japan and Korea.

However, PV manufacturing in Australia comes with challenges: it has a comparatively small domestic market, is geographically isolated, and currently has underdeveloped manufacturing capacity. The techno-economic analysis shows that for all steps in the supply chain, PV manufacturing in Australia will be more expensive than in China. Importantly, nevertheless, it is not a cost differential that is impossible to overcome.

Thus, in this section a thorough analysis of the relevant scale, sustainability considerations, Australia's overall competitive advantages and critical barriers for market entry per step of the value chain are outlined.

4.1. Poly-Si

4.1.1. Volume and Production and Timescale

Currently, Chinese polysilicon factories are announcing installation capacities exceeding 100 kt per annum, with 80 kt per annum considered their minimum capacity. However, after the evaluation of current and historical industry growth and stakeholder consultations, a production capacity of 25 kt per annum is deemed the minimum viable scale for economically sustainable production in Australia. This is due to the relatively limited domestic market as well as to ensure a feasible budget allocation request from the government. While we identify 25 kt as the minimum viable capacity, a size of 50 kt or higher would be preferable for achieving economies of scale, contingent upon export markets. Yet, decision by individual investors will be required with regard the actual size of a commercially viable poly-Si facility.

A production capacity of 25 kt per annum would yield enough poly-Si for over 10 GW per annum of PV production, which is equivalent to almost twice Australia's current annual demand. Such a factory would thus need to find export markets, which would tie it into a globally diversified solar supply chain. Nevertheless, as the local PV module demand increases towards 10 GW per annum, this 25 kt facility could then serve a 10 GW domestic market, or up to ~15 GW when accounting for the continual reduction in silicon consumption (tonnes per GW) due to increased module efficiencies and reduced silicon losses during wafer cutting and wafer thicknesses.

To establish poly-Si production in Australia, foreign partners will be required due to the lack of local expertise for this part of the supply chain. There are a number of potential partner companies to consider from a range of countries, including Germany, China, Korea and the US. It is noted that some Chinese companies are vertically integrated, which may allow strategic partnerships across the value chain. Several Chinese poly-Si producers are also actively looking to expand their production capacities outside of China.

Stakeholders have provided valuable insights into the differences in the timelines for building a poly-Si factory in Australia compared to China. In China, such factories can be constructed relatively quickly, taking less than 1.5 years for brownfield sites and around 2 years for greenfield sites, once necessary approvals are obtained. However, at present in Australia, the process is anticipated to be significantly longer, at least double that duration, owing to both the approval process and the actual construction phase.

Environmental approvals have been identified by stakeholders as a major factor contributing to the extended timeline in Australia. The approval process alone for industries with similar activities can take over three years. Additionally, delays in immigration approvals can further hinder the commissioning of the facility. These factors, coupled with the higher costs associated with importing specialised and heavy equipment required for poly-Si production, compound the time and capital expenditures for Australian manufacturers in an already CAPEX-intensive segment of the supply chain.

4.1.2. Sustainability Considerations

Polysilicon production is an emission-intensive process, primarily due to high electricity requirements for poly-Si purification (scope 2 emissions[110]), as well as value chain emissions related to mg-Si production (scope 3 emissions). A breakdown of the estimated emissions intensity for poly-Si production is presented in Figure 4-1. The use of natural gas and chemicals in poly-Si production have a comparatively minor impact on the overall emissions intensity. Therefore, poly-Si facilities would unlikely be captured under the existing Safeguard Mechanism.[111]

[110] Clean Energy Regulator, https://www.cleanenergyregulator.gov.au/NGER/About-the-National-Greenhouse-and-Energy-Reporting-scheme/Greenhouse-gases-and-energy, viewed 14 Aug. 2023

[111] DCCEEW, https://www.dcceew.gov.au/climate-change/emissions-reporting/national-greenhouse-energy-reporting-scheme/safeguard-mechanism#:~:text=The%20Safeguard%20Mechanism%20is%20the,gas%20emissions%20of%20these%20facilities , viewed 14th Nov 2023.

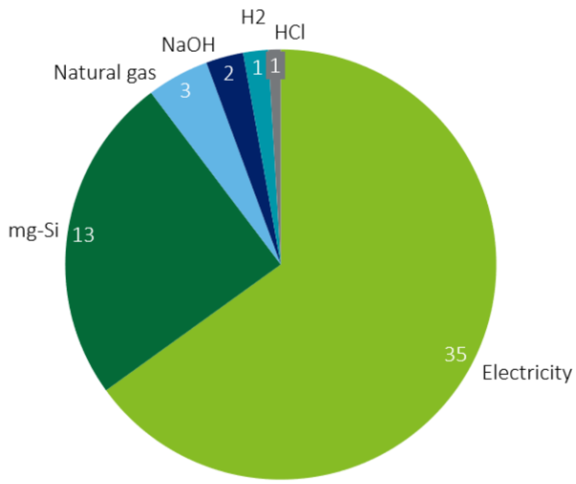

Figure 4-1: Poly-Si production - emissions intensity (t CO_2e/t poly-Si)

With a current average emissions intensity of Australian electricity at 622 g CO_2e/kWh,[112] the indirect emissions for poly-Si purification process are in the vicinity of 34.8 tonnes CO_2e /t poly-Si (1.71 Mt CO_2e per annum for a facility of minimum viable scale). Substantial reductions can be achieved through decarbonised electricity production. However, due to the large baseload power requirement for poly-Si purification, substantial scale up of low emissions firming is required in Australia to firm increased variable renewable energy supply. Poly-Si plants in China are already locating near hydroelectricity plants, both for emissions reductions considerations and reliable access to cheap electricity.

Mg-Si production is also emissions-intensive, at approximately 12 t CO_2e /t mg-Si. Approximately 50% of emissions can be attributed to electricity consumption, and 50% to the use of a reducing agent (typically coal). Coal-associated emissions can be reduced by substituting it with charcoal from timber plantations, which is considered emissions-neutral under carbon accounting frameworks. However, stakeholder consultation indicates an insufficient supply of charcoal in Australia to meet existing mg-Si production, particularly as the West Australian Government moves to ban the harvesting of native forests by 2024.[113] Expanding mg-Si production to support local poly-Si production would need to consider the lead time to establish new plantations, which can take 10-12 years, or use higher emission coal reductants. Alternative methods using Hydrogen as a reductant are also under investigation[114].

Chemicals produced as by-products during the poly-Si fabrication process need to be neutralised to allow safe disposal. This is achieved with the use of NaOH. Gas recovery systems are also required in the facility to greatly improve the utilisation of gases and minimise waste.

[112] AEMO, https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/market-operations/settlements-and-payments/settlements/carbon-dioxide-equivalent-intensity-index, viewed 24 Aug. 2023.
[113] https://www.abc.net.au/news/2022-05-17/silicon-manufacturer-may-have-to-import-coal-low-jarrah-supply/101060874, viewed 14 Aug 2023.
[114] Silicon production using hydrogen as reductant - Prosjektbanken (forskningsradet.no)

4.1.3. Australia's Competitive Advantage

Australia has existing strengths and sources of competitive advantage that make it an attractive location for future manufacturing of poly-Si. Building on this competitive advantage is key to attracting investment and building international partnerships, and may support the development of a globally competitive poly-Si industry.

- ***High quality wind and solar resources for decarbonised electricity supply*** - In the medium to long-term, Australia should be in a position to make firm renewable energy available to large-scale, energy-intensive manufacturing cheaper than most nations in the world. Australia's abundant space and high-quality wind and solar resources make it an ideal location for the generation of low-cost renewable energy to power energy-intensive industry. Australia is already the sixth largest producer of solar power in the world, generating 52 TWh of solar power in 2021, and has the second highest theoretical potential for solar power in the world.[115] This is reflected in the government's ambition of becoming a renewable energy superpower. Given the energy intensity of the poly-Si manufacturing process, abundance of renewable energy is not only critical for production of low carbon solar modules (particularly at the mg-Si and poly-Si stage), but also provides the opportunity for significant electricity price reductions as penetration of renewable energy sources increases and costs of green firming options come down. A target electricity price for firmed renewable energy is USD 50/MWh.
- ***Existing large-scale export credentials and infrastructure*** - Australia has the capability to finance and build large-scale production facilities and has a reputation as a trusted energy and minerals export partner as a global leader in liquified natural gas (LNG), coal and iron ore exports. This has resulted in a strong track record of scaling up large-scale infrastructure projects, as well as existing high-capacity ports and supporting infrastructure to transport and handle bulk exports. The above factors, in combination with Australia's proximity to the Asia-Pacific market, should provide an advantage for future export-focussed poly-Si manufacturing.
- ***Stringent health and safety standards*** - Polysilicon manufacturing requires the use and storage of both trichlorosilane (TCS) and hydrogen as input materials, both of which are highly flammable/combustible and classified as hazardous chemicals under workplace health and safety laws. Australia's existing experience in high-risk industries such as LNG, mining and university R&D, coupled with rigorous health and safety regulations make it an attractive choice for establishment of a poly-Si industry.
- ***Labour and employment conditions*** - Concerns around human rights abuses in the Xinjiang region in Western China, particularly in the poly-Si manufacturing industry, have resulted in increased scrutiny of solar supply chain transparency over the past few years. As such, stringent legislation on employment conditions in Australia presents a particular advantage for poly-Si and solar module off-takers and investors with high supply chain transparency standards. Australia also has a range of training institutions for up-skilling the workforce required for manufacturing.

[115] Austrade Benchmark Report (2023), https://www.austrade.gov.au/benchmark-report/renewable-energy-superpower, viewed 20th Aug 2023.

- ***High quality quartz deposits and silicon as a critical mineral –*** Australia has large deposits of high quality quartz; while this is not geographically unique, international stakeholders have identified this as an attractant for investment. In addition, the government has identified silicon as a critical mineral under the Australian *Critical Minerals Strategy 2023 – 2030*. Objectives of the strategy include building sovereign capability in critical minerals processing, and extracting more value from onshore resources, particularly for priority technologies identified by the government.[116] While it is unclear whether mg-Si or poly-Si production may receive direct support for the solar value chain under this framework, strategic alignment may facilitate support for the silicon solar value chain in future.

4.1.4. Barriers

The primary barrier for manufacturing of poly-Si in Australia is the higher cost of production compared to existing incumbents in China, resulting in an estimated economic gap of USD 7/kg poly-Si produced. This is primarily driven by three key factors:

- **High electricity price and future price uncertainty** – Australia currently has relatively high electricity prices compared to several global peers, particularly those with abundant and cheap hydroelectric power such as China, Canada and the Nordic countries. In addition, price increases and volatility in the wholesale electricity market over the past year have led to additional price uncertainty.
- **High upfront capex** – this includes higher costs related to construction (material, labour and land), import of international equipment (e.g., from the modification of equipment to meet higher safety and environmental standards and shipping costs) and import of expertise for commissioning.
- **Access to low-cost mg-Si** – In China, the cost of mg-Si is reported to be around USD 2/kg, on top of which a 55% import tariff is applied for import to Australia. There is existing mg-Si production in Australia which could potentially be accessed, however, the market price of mg-Si produced outside of China is around USD 4/kg.

In addition to underlying cost drivers, stakeholder consultation identified the following barriers for establishment of a poly-Si facility.

- **Permitting and approval uncertainty and timeline** – Stakeholders highlighted investment uncertainty related to approvals and permitting outcomes. This is due to the lack of precedence or tailored guidance for major chemical/poly-Si facilities in Australia, complexities through interaction of federal and State approvals, as well as the potentially lengthy and unknown approval processing timeframes. Indicative approval timelines of 3+ years are considered likely for a poly-Si facility which, in addition to longer construction timelines, would significantly impact speed to market.
- **Access to international technology and skilled labour** – Australian companies will likely be dependent to a degree on international technology intellectual property (IP) and skilled

[116] Australian government, https://www.industry.gov.au/publications/critical-minerals-strategy-2023-2030, viewed 28th Aug 2023.

workers to set up, operate and train workers for a state-of-the-art poly-Si plant. Sufficiently attractive visa options to attract and retain appropriately skilled workers is perceived as a key barrier to attract appropriate players to Australia.

- Uncertain foreign investment approvals processes is also seen as a barrier.

4.2. Ingot/Wafer

4.2.1. Volume and Production and Timescale

Through the consultation process carried out as part of this study, a facility of 1 GW per annum capacity has been selected as the minimum viable scale of production for Australia. However, given the size of capacity expansions in China, factories of 2 - 5 GW per annum could be considered, noting that local offtake would require at least the same volume of cell production, and a 2 GW per annum factory would represent 40% of current PV demand in Australia. This report assumes that 1 GW per annum is a minimum viable size for facility and a decision by individual investors is required with regard the actual size of a commercially viable facility.

For establishing production, two key options exist whereby an expertise base could be established in Australia. Firstly, partnering with a foreign company to establish production. Overwhelmingly, the state-of-the-art technology for ingot and wafering is located in China. This may be a suitable option to increase likelihood of wafer offtake in the event that wafer production exceeds cell production in Australia. Secondly, there are turnkey options available for ingot/wafering such as from JSG or Linton in China. Turnkey lines offer packages with guaranteed performance and training. Although this represents a higher upfront cost, the use of turnkey lines is an appropriate market entry strategy for new players. Once a production facility is up and running, and local expertise has been built, future capacity expansions can 'cherry pick' equipment toolsets to ensure the lowest capital cost and the highest performance for production lines. Note, however, the Chinese government has recently moved to prevent the export of ingot/wafer technology, which will likely determine which route ends up being possible.

To establish an ingot/wafering facility at a green field site in China, approximately 6 months are required after approvals are obtained, substantially shorter than that required for establishing a poly-Si production facility. In Australia, and not unlike other Western countries, the required time for ramping-up these operations would likely be in the 12 – 18-month after all the permitting has been cleared.

4.2.2. Australia's Competitive Advantage

Although the primary cost drivers underlying manufacturing of ingots/wafers do not naturally favour Australia (cost of labour and high upfront capex), Australia is not highly disadvantaged in these categories compared to other OECD states such as the US.

Furthermore, ingot and wafer facilities are considered 'hard to do' given the high level of specialisation and limited access to technology and IP. Stakeholder consultation indicates that the support for ingots and wafers under the US Inflation Reduction Act (IRA) will be largely under-represented compared to steps further down the value chain such as cells and modules. As such, there is likely to be less global competition and more global demand at this stage of the value chain, with the potential for Australia to capitalise on alternative comparative advantages outlined below:

- *History of collaboration with China in the PV industry -* Compared to other countries, Australia has a history of close collaboration with China in the PV industry, particularly in the cell and modules stages. For example, many Chinese engineers involved in the early days of the Chinese PV industry development were trained in Australia, while Australian experts played a critical role in establishing early Chinese PV manufacturing lines[117]. This collaborative history in cell/modules technology could cement advantages and opportunities when requiring Chinese expertise to establish local ingot/wafer production in Australia through a joint venture or other commercial arrangements.
- *High quality wind and solar resources for decarbonised electricity supply –* As outlined in poly-Si above, in the medium to long-term, Australia should be in the position to make firm renewable energy available to large-scale, energy-intensive manufacturing cheaper than most nations in the world. With electricity contributing approximately 10% of the total cost of ingot and wafer production and the majority of emissions in Australia, this may become a competitive advantage for Australia over time and with increased attention on value chain emissions.

4.2.3. Sustainability Considerations

The main sustainability considerations come from the emissions associated with the use of electricity. The electricity requirement of approximately 65 MWh/MW, results in 41 tonnes CO_2e /MW of emissions assuming the current mix of energy generation in the NEM, which has an emissions intensity of 0.622 kg CO_2e/kWh. As discussed for poly-Si purification, the use of green electricity can largely eliminate these emissions.

4.2.4. Barriers

The primary barrier for manufacturing of ingot/wafer in Australia is the higher cost of production compared to existing incumbents in China, resulting in an estimated economic gap of US 3.7c/W ingot/wafer produced. This is primarily driven by:

- **Cost and availability of skilled workers** – The cost of both construction and production labour in Australia is high compared to China and the OECD. This has an impact not only on ongoing production costs, but also upfront construction and CAPEX (noted as depreciation in the cost analysis). Additionally, Australia currently has a large shortage of skills in the clean energy industry, which could drive wages up further. A key factor for success will be access to highest levels of automation and manufacturing excellence.
- **High electricity price and future price uncertainty** – While less significant compared to poly-Si, electricity represents approximately 10% of the estimated ingot/wafer production costs in Australia. Australia currently has relatively high electricity prices compared to several global peers, particularly those with abundant and cheap hydroelectric power such as China, Canada

[117] M. Green, "How did solar cells get so cheap?", https://www.sciencedirect.com/science/article/pii/S254243511if using 0090X, 20th Mar 2019.

and the Nordic countries. In addition, price increases and volatility in the wholesale electricity market over the past year have led to additional price uncertainty.

In addition to underlying cost barriers, stakeholder consultation identified the following barriers for establishment of an ingot/wafer facility.

- **Access to Chinese IP and equipment** – According to data from the IEA, China accounted for 97% of global wafer production in 2021. In early 2023, the Chinese government announced the potential to limit exports of Chinese ingot/wafer IP and equipment to other countries, in an attempt to maintain competitiveness.[118] The potential export ban on this state-of-the-art equipment would present a significant challenge to establishing ingot/wafer capacity in Australia – although this may be offset in part by Australia's history of collaboration with the Chinese PV industry. The proposed restrictions are currently still under consultation with outcomes uncertain at the time of this study.
- **Uncertainty about foreign equity position –** A joint venture with an international firm with the appropriate technology and IP knowledge would be a feasible pathway to establish ingot/wafer capacity in Australia. However, stakeholders have indicated high uncertainty around foreign investment approvals in Australia overseen by the Foreign Investment Review Board (FIRB), with regards to both timing and outcome.
- **Access to international skilled labour –** In addition to the technology IP and equipment outlined above, Australian companies will likely be dependent, in the early stages, on international skilled workers to set up, operate and train the domestic workforce for a state-of-the-art ingot/wafer plant. Sufficiently attractive visa options to attract and retain these workers is perceived as a barrier for companies considering a joint venture with an international company in Australia. In particular, English language requirements for visas were identified as a particular barrier for Chinese stakeholders consulted.

4.3. Cell

4.3.1. Volume and Production and Timescale

Typically, Chinese TOPCon manufacturers are building at least 10 GW per annum of production capacity each. However, production line equipment sets are typically in the range of 500 MW per annum each. The minimum viable production size assumed for Australia is 1 GW per annum, although a more optimal value is 2 GW per annum. This allows for improved redundancy between tools, allowing for maintenance cycles of individual tools without disrupting the entire production line. To build a new facility in China, 3-6 months are required, followed by 1 month for tool installation. Outside of China, this lead time could be up to 5 times longer, particularly with approvals required for dangerous gases.

[118] PV Magazine, https://www.pv-magazine.com/2023/01/30/china-plans-to-introduce-restrictions-on-polysilicon-wafer-exports/, viewed 13th Aug 2023.

4.3.2. Sustainability Considerations

Cell fabrication processes use approximately 45 MWh of electricity per MW, translating to an emissions intensity of 28 tonnes CO_2e/MW, which can be greatly reduced when using green electricity as discussed in section 4.1.2. There are also emissions related to the manufacture of chemicals used in the process, however the majority of the emissions come from the use of electricity. Further improvements in the emissions intensity of cell production could be achieved by improving cell efficiencies, thereby increasing the power per unit of energy used, and working with suppliers of large bulk chemicals such as NaOH and N_2 for options to decarbonise the production of those materials.

A key sustainability consideration for cell fabrication is related to the responsible consumption of resources, and the ability to have a stable PV industry without impacting module prices. In particular, a material of concern is silver, which is common to all three dominant silicon solar cell technologies. Although GW scale production can certainly be done in Australia with the quantities required, consideration must also be given to the global context of PV production elsewhere, and the overall impact on global silver supply. In 2022, the PV industry used approximately 15% of the global primary silver supply. This was primarily for producing PERC. Current values for PERC range between 5 – 10 t/GW. However, the current shift to TOPCon could potentially double the silver demand. TOPCon solar cells currently require 12 – 20 t/GW. It is also noted that mainstream screen-printed SHJ uses more than double the silver as PERC due to the use of low-temperature silver pastes for both contacts, with current estimates in the range of 17 - 28 t/GW. It is noted that leading solar cell manufacturers for all technologies have consumption values substantially lower than that reported in the 2023 ITRPV.

With these consumption levels, the global PV industry could fabricate 500-1000 GW per annum of PERC, 250 - 420 GW per annum of TOPCon or 180 - 300 GW per annum of SHJ using 20% of the global primary silver supply. To allow TW scale of TOPCon manufacturing per annum globally, consumption of silver needs to more than halve. To achieve this, the industry will need to continue with rapid reductions, as has been demonstrated over decades. It is noted that in the laboratory, silver-free screen-printed options already exist for TOPCon, although with CRI[119] levels too low to consider as viable for this study. For SHJ, silver consumption needs to reduce by a factor of 4, presenting a much larger challenge than for TOPCon. Alternatively, copper plating can essentially eliminate silver consumption, although it represents a significant deviation from current mass-manufacturing practices. Note that copper is a fast-diffusing impurity with the potential of severely reducing cell efficiencies if found in the bulk of the silicon wafers. Copper plating is most suitable for SHJ given the natural copper-diffusion barrier in the form of the transparent-conductive-oxide layer, as is used by Sundrive.

Other sustainability considerations include the use of chemicals and waste management. Consultation with industrial solar cell manufacturers in China indicate an increasing emphasis on safety and environmental considerations. This includes a shift away from the use of nitric acid in production to ease the management of chemical waste, and challenges in approvals for certain chemical

[119] ARENA, "Commercial Readiness Index for Renewable Energy Sectors", published Feb. 2014

processes,[120] although this is not relevant for the mainstream TOPCon technology chosen for this study.

With any change in cell technology, material supply chain and sustainability challenges must be considered for all materials. In particular, for SHJ an additional material to consider is indium.[121] However, indium-lean and indium-free options exist in industrial R&D environments.[122]

4.3.3. Australia's Competitive Advantage

Similar to ingots/wafers, the primary cost drivers underlying manufacturing of cells do not naturally favour Australia (high cost of labour and high upfront capex). However, as noted, Australia is also not highly disadvantaged in these categories compared to other OECD states such as the US and EU. Due to the anticipated technology improvements and reductions in material consumption over time outlined above, Australia may be well positioned to capitalise on alternative comparative advantages:

- ***IP & expertise: Australia's track record in developing cell technology*** **–** Australia has a long history of expertise in cell technology development, responsible for the development of the PERC and TOPCon cell architectures, and implementation processes into cell production to improve device performance, improve reliability and reduce cost, such as the development of the advanced hydrogenation technology. Another example is Australia's long history of developing copper plating technology, which has been used in mass production by BP solar and Suntech and is now being explored for mass production of SHJ solar cells by Sundrive. Australia also had a globally significant cell and module manufacturing capacity through Tideland Energy, BP Solar and Solarex through the late 90's and early 2000's. Once cell manufacturing in Australia is re-established, further improvements in technology can capitalise on this ongoing innovation and expertise in country.
- ***History of close collaboration with China*** **–** Whilst Australia lacks manufacturing capabilities of semiconductor devices like solar cells compared to the US and EU, a new cell manufacturing industry can leverage the long-standing relationship in the solar industry to Chinese manufacturers and expertise.
- ***High quality wind and solar resources for decarbonised electricity supply*** **–** As outlined in poly-Si and ingots/wafers above, in the medium to long-term, Australia should be in a position to make firm renewable energy available to large-scale, energy-intensive manufacturing cheaper than most nations in the world. With electricity contributing approximately 12% of the total cost of cell production and the majority of total emissions in Australia, this may become a competitive advantage for Australia over time and with increased attention on value chain emissions.

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[120] Challenges for approvals of chemical plating (metals) for management of metallic liquid waste.
[121] Y. Zhang et al. Energy and Environmental Science 2021, 14, 5587 – 5610. https://pubs.rsc.org/en/content/articlehtml/2021/ee/d1ee01814k
[122] C. Yu et al. Nature Energy 2023, https://www.nature.com/articles/s41560-023-01331-7

4.3.4. Barriers

The primary barrier for manufacturing of cells in Australia, other than the overall lack of manufacturing infrastructure and experience, is the higher cost of production compared to existing incumbents in China, resulting in an estimated economic gap of USD 5 c/W of cells produced. This is primarily driven by:

- **Cost and availability of skilled workers** - The cost of both construction and production labour in Australia is high compared to China and the OECD. This has an impact not only on ongoing production costs, but also upfront construction and CAPEX (noted as depreciation in the cost analysis). Additionally, Australia currently has a large shortage of skills in the clean energy industry, which could drive wages further upwards.

In addition to underlying cost drivers, stakeholder consultation identified the following barriers for establishment of a cell facility:

- **Supply chain concerns** - Two primary concerns are access to high-purity semiconductor-grade chemicals and silver pastes. Local suppliers lack the necessary scale and purity of the chemicals and silver pastes which are the major conversion cost components (32% in Australia) and will rely on IP-protected technologies, making their supply challenging.
- **Permitting and approval uncertainty and timeline –** due to the nature of cell manufacturing as large-scale chemical facilities and the lack of precedence of these types of facilities in Australia, stakeholders highlighted investment uncertainty related to approvals and permitting outcomes due to the lack of tailored guidance, additional complexities through interaction of federal and State approvals, as well as the potentially lengthy and unknown processing timeframe.

4.4. Module

4.4.1. Volume and Production and Timescale

Module assembly is already available in Australia with Tindo Solar, located in South Australia, and is the most accessible sector for newcomers due to its low capex and electricity requirements per GW of production, along with its relatively safe operational environment. With a minimum viable production scale of 1 GW, module fabrication offers the quickest potential capacity buildup, benefiting from simpler processes and fewer safety hazards compared to earlier supply chain stages involving chemicals and gases. While a workable scale starts at 1 GW, most manufacturers overseas opt for the design of 2-5 GW scale plants from the beginning, ramping up operations in phases until the maximum capacity for the site is reached.

To establish a new module assembly facility in China requires as little as three months to build the facility after approvals have been obtained, with an additional 1 month to install equipment and begin ramp-up.

4.4.2. Sustainability Considerations

The electricity requirements for module assembly are relatively small, translating to a substantially smaller emissions contribution than other parts of the solar value chain. The electricity related emissions for module production are approximately 7.8 tonnes of CO_2e/MW. However, many of the emissions are hidden in materials used, such as the aluminium frames. For every tonne of aluminium, approximately 14 MWh of electricity are required, representing approximately half of the emissions of aluminium at 12 – 16 tonnes of CO_2e per tonne of Aluminium. This translates to emissions from the module of approximately 84 tonnes CO_2e/MW. Substantial reductions in the emissions contributions of module frames to PV modules can be obtained by using green electricity. Capral Aluminium has recently announced new green aluminium products with an emissions intensity as low as 4 tonnes CO_2e/t aluminium, a 75% reduction from the global average.[123] The Elysis project for developing low-carbon aluminium products, has also announced the elimination of direct emissions from aluminium smelting, meaning there is potential to reduce the emissions intensity of primary aluminium to well below 2 t CO_2e/t aluminium when using green electricity.[124]

Another high source of emissions for the module is glass. With glass usage at approximately 40 g/W, and the emissions intensity of glass production at 0.75 kg CO_2e/kg glass, this contributes approximately 30 tonnes of CO_2e/MW. Emissions reductions for glass are harder to achieve than that for silicon purification or aluminium smelting. This is due to the limited use of electricity in the current process and challenges in increasing electricity for high heat processes, as well as challenges in replacing natural gas with hydrogen.

With cells only comprising 3-5% of the total weight of a module, local manufacturing in Australia has the opportunity to reduce shipping emissions. However, as over 80% of the weight of a PV module is aluminium and glass, this would require local production of aluminium and glass components.

4.4.3. Australia's Competitive Advantage

With regards to process complexity, technical expertise and time to establish a manufacturing facility, module assembly is considered a relatively 'easier' step in the value chain. This is reflected in the geographic diversity in existing module assembly around the world compared to other value chain steps, which are more highly concentrated. As such, Australia's competitive advantage may be relatively lower in the module assembly stage than e.g., poly-Si and ingot/wafer manufacturing, due to existing increased competition on the global scale. However, the following factors may contribute to Australia developing a competitive advantage, particularly from an end-to-end supply chain perspective in future:

- **Large domestic market potential** – Australia is among the countries with the highest solar power potential in the world, making it a highly attractive country to generate solar energy. AEMO predicts in its "step change" scenario that annual PV additions in Australia will range between 4 and 8 GW over the next 20 years. If Australia wants to realise its ambition of becoming a hydrogen superpower, this annual number doubles to 15 GW per year by 2045. These developments present a significant domestic market potential for module manufacturers in Australia.

[123] Capral Aluminium, https://www.capral.com.au/blog/news/capral-introduces-local-lower-carbon-aluminium-for-australian-manufacturers/ , viewed 20th Aug 2023.
[124] Elysis, https://www.elysis.com/en , viewed 25th Aug 2023.

- **Existing glass and aluminium industry in Australia –** The two largest material inputs to module assembly are solar glass and aluminium. 1 GW of solar panels would require approximately 40,000 tonnes of glass and 6,000 tonnes of extruded anodised aluminium frames (equivalent to the existing production of Capral). While there is no existing solar-grade glass production in Australia, and existing production and scale of aluminium is not yet positioned for cost competitiveness, development of a domestic module assembly capability at scale presents an opportunity for Australia to leverage and expand the existing Australian glass and aluminium industry. This may also unlock additional benefits around supply chain security, increased domestic manufacturing complexity, and economic opportunities for Australia in an end-to-end value chain development scenario. In addition, as over 80% of the weight of a PV module is aluminium and glass, utilisation of domestically produced aluminium and glass could significantly reduce shipping emissions.

4.4.4. Barriers

The primary barrier for manufacturing of modules in Australia is the higher cost of production compared to existing incumbents in China, resulting in an estimated economic gap of US 3.5c/W per module produced. This is primarily driven by:

- **Material costs and reliance on overseas suppliers** – Material costs make up over 70% of the total cost of production in module assembly, particularly driven by the cost of aluminium extrusions and solar glass. While the cost analysis conducted in this study assumes material sourcing from China (and hence marginal difference in material costs, primarily related to shipping), future sourcing of these materials from Australia may increase the cost differential to China even further. In addition, exposure to global market dynamics of key input materials and reliance on overseas suppliers was stated by industry as a key barrier for module assemblers. In particular, stakeholders identified the challenge of bill of materials (BOM) payment terms, with pre-payment of materials required prior to shipping to Australia, resulting in cash flow issues during lengthy shipping operations (up to 3 months), and lack of flexibility to respond to short-term fluctuations in market pricing.
- **Cost of labour -** While the cost of labour only contributes approximately 6% to the overall cost of module production in Australia, this is the second largest contributor to the cost differential between China and Australia, with Chinese labour only accounting for less than 2% of total production cost. Additionally, Australia currently has a large shortage of skills in the clean energy industry, which could drive wages further upwards.

In addition to underlying cost drivers, stakeholder consultation identified the following barriers for establishment of a module facility.

- **Demand uncertainty for premium priced products** – Although module offtakers have indicated that there is an appetite for Australian-made, environmental, social and governance (ESG) conscious and low carbon modules, there is high uncertainty around sustained market demand if the modules are sold at a premium price compared to overseas modules, with an unlikely voluntary willingness to pay a premium in the absence of mandated local content/low carbon/supply chain transparency requirements. Concerns around dumping of cheaper overseas products as a market response strategy were also raised by stakeholders and would need to be addressed in the future.

- **Lack of module certification capability in Australia** – Stakeholders indicated that a lack of module certification capability in Australia is a key barrier to rapid product development, due to the requirement for re-certification of modules for any changes to the bill of materials (which could be induced due to e.g., supply chain shortages). Currently, re-certification of modules requires them to be sent overseas, taking 3 – 4 months and costing AUD5,000 – 15,000 each time. Evidence from stakeholders indicates that several large-scale module manufacturers in China have in-house testing facilities to speed up the process, facilitating a cheaper and more rapid response.

4.5. Location Considerations for PV Industry Establishment in Australia

For the establishment of solar value chain manufacturing capability in Australia, there are several location considerations that are relevant to all or several steps of the value chain. In particular, given the different characteristics of each step outlined above, location considerations vary between steps of the value chain. A summary of location considerations across each step is provided in Figure 4-2.

	POLY-SI	INGOT/WAFER	CELL	MODULE
Proximity to upstream supply chain players	Medium	Medium	Low	High
Proximity to downstream supply chain players	Low	Low	Low	High
Access to a skilled workforce	High	Medium	High	Low
Availability of low-cost renewable electricity	High	Medium	Low	Low
Existing supportive policy/programs	High	High	High	High
Proximity and access to supporting infrastructure	High	High	High	High
Existing industrial hubs	Medium	Medium	Medium	Medium

Figure 4-2: Importance of consideration in the location selection of the solar PV supply chain segment

Each consideration is explored further in appendix G.

4.6. End-of-Life Options for PV Panels[125]

Solar module recycling will be a crucial part of Australia's transition to a sustainable renewable energy future. Good product stewardship will go hand in hand with the strong social licence required for a fast deployment of many GWs of solar modules. The recycling challenge is irrespective of the origin of module manufacturing but will need to be addressed even more stringently if Australian taxpayers are required to initially support the build-out of domestic solar manufacturing.

As the installation of panels in Australia increased exponentially in the early 2000s, there will be a rapid increase in the number of panels reaching the end of their 25-30-year lifespan within the next few years. Approximately 90% of existing PV systems in Australia could ultimately end up in landfill if regulatory and technological advances are not made[126]. Si-based PV panels contain small amounts of lead, which can leach out and affect the environment and human health if not disposed of correctly.

PV panels are comprised of valuable materials, with huge recovery potential. Glass, aluminium, silicon, copper and silver are the main constituents of the most commonly installed PV panels in Australia. Research and development of novel PV recycling processes for decommissioned panels have achieved recycling rates of up to 95%,[3] although recovering materials at a high purity is complex and hard to achieve. These valuable recovered materials could be fed back into the PV supply chain, or diverted to other industries, promoting a circular economy, resulting in increased environmental and economic benefits (see Figure 4-3). This is particularly beneficial when considering local manufacturing for PV panels, as recovered materials can then also be reused locally, eliminating the need for exporting or diverting these materials elsewhere.

[125] Extract from: R. Deng, V. Tan, C. Niu, R. Egan (2023) Scoping Study: Solar Panel End-of-Life Management in Australia, ACAP UNSW.

[126] UNSW, https://www.unsw.edu.au/news/2023/06/repair--reuse-and-recycle--dealing-with-solar-panels-at-the-end-#:~:text=The%20management%20and%20disposal%20of,off%20points%20to%20be%20recycled, viewed 13 Aug 2023

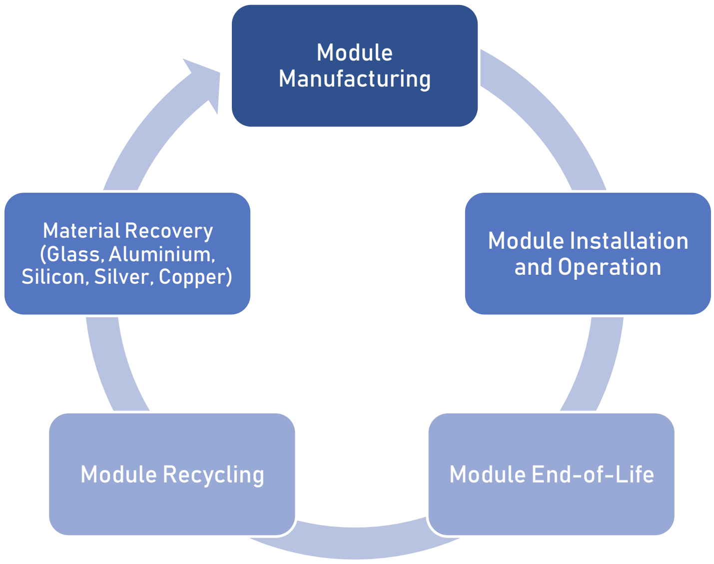

Figure 4-3: PV module manufacturing and recycling cycle.

4.6.1. Size of the Problem

The cumulative volume of end-of-life solar panels in Australia is projected to reach 280,000 tonnes by 2025 and exceed 1 million tonnes by 2035. More than 80% of decommissioned solar panels will be generated from small-scale distributed PV systems until 2030 due to the early development of Australia's residential PV market. The waste panels from large-scale systems will begin to catch up after 2030 and increase at a much faster rate than the waste from small-scale systems. This is illustrated in Figure 4-4.

The volume of end-of-life solar panels is expected to grow rapidly in New South Wales, Victoria, and Queensland particularly and is highly concentrated near all capital cities. This suggests that the PV recycling industry in Australia should begin with the major cities and then expand to regional Australia.

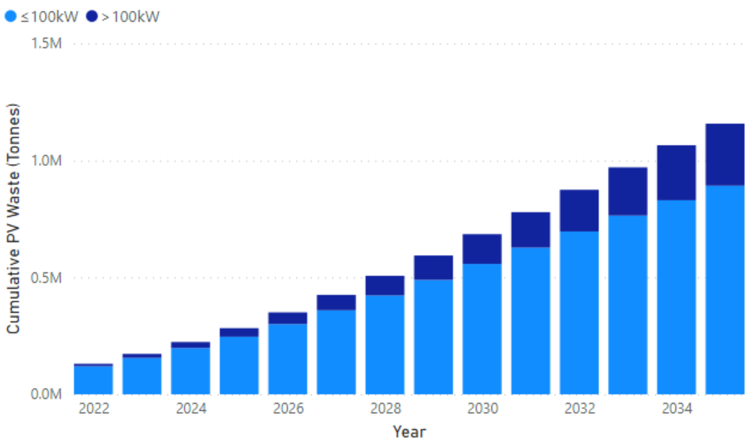

Figure 4-4: Cumulative PV waste in tonnes in Australia from 2022 to 2035, showing waste from small and large-scale systems[127].

4.6.2. Current State of PV Recycling in Australia

Currently, Australia does not have a federal PV panel recycling scheme in place. Most panels across the country are sent to landfills at the end of their lifetime. The Australian Government has committed

[127] R.Deng, V.Tan, C.Niu, R. Egan (2023) Scoping Study: Solar Panel End-of-Life Management in Australia, ACAP UNSW.

to develop a mandatory product stewardship scheme to reduce waste from small electrical products and solar photovoltaic systems and is currently in the consultation phase. This will apply to both small-scale (up to 100 kW) and large-scale (over 100 kW) PV systems, with differing obligations for both system types. For example, large-scale PV system owners will need to submit a decommissioning plan which details how the system will be decommissioned, how products will be recycled, and how hazardous waste will be managed. The scheme is still under consultation, and as such, specific details regarding the recycling process and expected material recovery rates are not available. However, the scheme will aim to re-use valuable recovered materials in the PV supply chain where possible[128].

Victoria is the only state to have banned solar panels from landfill – panels need to be taken to e-waste drop off points to be recycled. However, the current PV recycling services that do exist in Victoria can only recycle a small fraction of a panel by weight[129], due to the lack of technical capability.

Under a new proposed recycling expansion program, Queensland will soon ban PV waste from going to landfill. However, this is only expected to be enforced over the next decade [130].

4.6.3. Technical Options for PV End-of-Life

Even though the silicon solar cell structure has changed over the years to achieve higher efficiency, the configuration of the module has barely changed since the 1980s. As it was shown in Section 3, at a high level the traditional crystalline silicon photovoltaic module is a combination of material layers protecting the solar cells from ambient conditions. A tempered glass sheet and a backsheet (sometimes another tempered glass sheet) encapsulate the active cell layer using EVA as the glue, to prevent it from environmental damage during outdoor operation. Aluminium frames and a junction box are attached to the outside of the panel, to provide extra mechanical strength and a terminal to output electricity. The solar cells contain valuable materials such as high-purity silicon and silver. The cell layer is approximately 4% of the total weight but 40%-50% of the value.

Based on this structure, solar panel recycling can be viewed as a "reverse engineering" process following three key steps: detaching the frame and junction box, delaminating the "sandwich" structure to get glass, solar cells, backsheet, ribbons or a mixture of them, and then extracting high-purity valuable material. The delamination step can be further divided into delamination and material sorting. Efficient material sorting can concentrate materials into certain groups to make subsequent material extraction easier.

The delamination is the most challenging step, and different approaches have been developed to achieve better separation efficiency and lower environmental impact. Figure 4-5 summarises feasible technologies that have been demonstrated at pilot or commercial scale.

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[128] DCCEEW, https://www.dcceew.gov.au/environment/protection/waste/e-waste, viewed 13 Aug 2023.
[129] Victoria Government, https://www.sustainability.vic.gov.au/recycling-and-reducing-waste/product-stewardship/national-approach-to-manage-solar-panel-inverter-and-battery-lifecycles , viewed 28th Aug 2023.
[130] Queensland Government, https://www.qld.gov.au/environment/management/waste/recovery/reduction/draft-e-products-action-plan, viewed 13th Aug 2023.

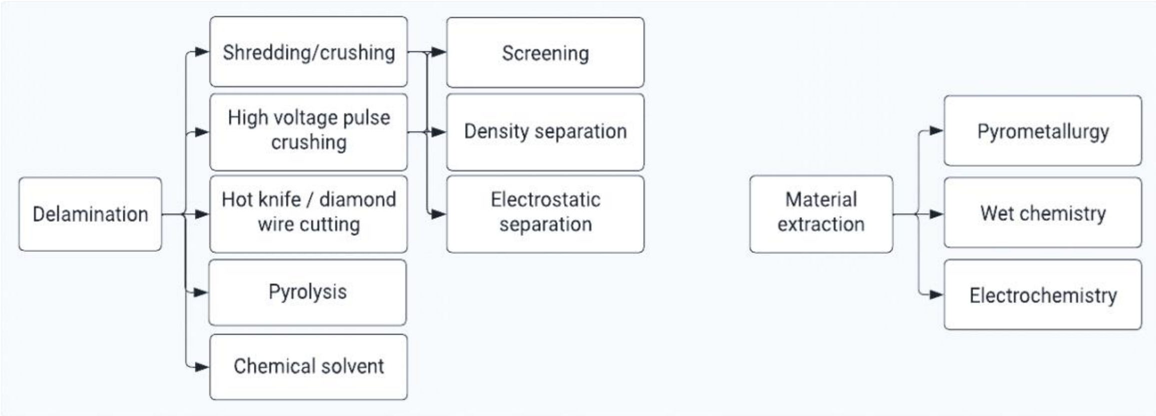

Figure 4-5: Feasible silicon solar panel recycling technologies

PV recycling activities can be divided into four categories:

Option 1: Delamination only - The recycling facility delaminates panels by shredding, crushing or other processes, sorts the materials and then sends fractions with valuable materials (silicon, silver, copper) to a downstream recycler for refinement. Overall costs, including capital, labour, maintenance, transport, land, buildings and utilities are estimated to be approximately AUD 500/t for a plant processing 5000t per annum.

Option 2: Full recycling - The recycling facility delaminates panels, separates and recycles all valuable materials. This option requires higher capital investment but is able to recover all valuable materials. Cost estimates are around AUD 980/t for 5000t per annum.

Option 3: Aluminium recovery only - In this option, the recycling facility only takes apart aluminium frames and junction boxes from the panels and leaves the rest untreated. Costs are around AUD 380/t for 5000t per annum.

Option 4: Reuse - panels undergo in-house performance testing, followed by sorting and packaging for re-sale. Costs are around AUD 250/t for 5000t per annum. Understanding that any failing module – which is not uncommon - will also need to be recycled.

4.6.4. Economic Value

Table 14 and Figure 4-6 show the breakdown of the component and value in a typical 20-kg crystalline silicon solar panel. On average, AUD 22.6[131] worth of materials can be potentially recovered from a typical 20-kg solar panel, resulting in a material value of over AUD 1000 per tonne of solar panels. Extrapolating this data, the total material value from all end-of-life solar panels generated in Australia is projected to exceed 1 billion dollars by 2033.

[131] Based on Deng et al. "A techno-economic review of silicon photovoltaic module recycling", July 2019.

Table 14: Typical silicon module weight and value (AUD) component breakdown[58]

Component	Material	Weight	Price (AUD/kg)
Solar cells	Silicon	3-5%	3.1 - 3.8
	Silver	0.03%-0.05%	746 - 1084
Ribbon	Copper	0.8%	7 - 10
	Tin	0.1%	22
	Lead	0.01%	3
Frame	Aluminium	16-20%	2.1 - 2.8
Glass	Glass	67-70%	0.06 - 0.13
Junction box	Copper	0.3%	7 - 10
Encapsulant	EVA	6-7%	Negligible
Backsheet	PVF/PET	3-4%	Negligible

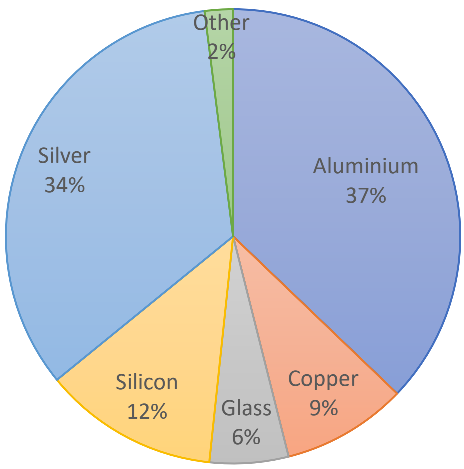

Figure 4-6: Value composition breakdown by percentage of major materials in a typical module according to Table 14.

5. Policy assessment – What Would It Take to Make Domestic PV Manufacturing a Reality

Establishment of a domestic solar PV supply chain would make Australia more resilient to supply chain shocks (both price and availability) and can provide a secure supply of solar PV panels, critical for Australia to achieve net zero emissions by 2050 and seize the opportunity to become a renewable energy superpower. However, Section 3 identified the fundamental cost gap to manufacture in Australia compared to China, and hence the decision to establish a domestic manufacturing capability comes with the need to bridge the cost gap with government support.

The policy analysis presented in this work is structured around this question:

If Australia defines domestic solar PV manufacturing as a strategic national priority – what policy levers could support the development of a viable, relevant, and timely industry, and what is the associated cost?

5.1. Policy Assessment Methodology

The policy analysis is based on a foundation of extensive stakeholder engagement, to understand critical barriers faced by industry (both incumbent and potential market entrants) to establish manufacturing capability in Australia across the value chain, and support required to overcome these barriers. Policy levers are considered under three overarching categories:

- **Enabling support** to target a range of non-financial barriers which may otherwise inhibit solar PV industry development.
- **Demand support** both direct and indirect, to address investment and offtake uncertainty for Australian produced products.
- **Supply support** to provide direct or indirect financial support to bridge the cost gap versus imported products.

A long-list of policy options was developed to understand the spectrum of support options available to incentivise solar PV manufacturing across each of these categories. This was based on a comprehensive review of policy actions undertaken by comparable jurisdictions in both solar manufacturing and adjacent sectors. The long-list of policy options is presented in Appendix C.

A selection of the most suitable and effective policies for the Australian context were then shortlisted for further assessment. The policy assessment was guided by the overarching policy principles presented below. These were considered as part of the policy shortlisting process, as well as through suggested policy design and implementation considerations included in the final recommendations.

5.1.1. Policy Principles

- Policy should be designed not to negatively impact the cost/speed of the Australian energy transition.
- Policy should not notably impact the delivered cost of solar electricity taking into account safety, reliability and affordability.

- Policy should stimulate long-term domestic economic additionality and crowd-in private investment.
- Policy should be designed to support broader government goals, such as emissions reductions, social outcomes and sustainability objectives.
- Policy should aim to achieve broad political support.
- Policy should maintain a commitment to principles of open and transparent markets and diversified trade relationships, recognising the opportunity to strategically enhance existing trade relationships.
- Policy should encourage investment from Australian and international sources into solar manufacturing facilities in Australia, alongside other sources of capital and ensure a public return to Australian taxpayers.
- Policy should avoid overly complex and uncertain administrative application processes and strive for clarity and simplicity for industry.

An extensive policy mechanism review of short-listed options was completed, including evaluation of Australian and international case studies and their successes and failures. In addition, quantitative analysis of supply-side levers was conducted, to estimate the impact of financial support on the cost of PV manufacturing in Australia. This included analysis of the effectiveness of each lever to close the cost gap to the equivalent import price from China, which is considered to be the price point at which Australian manufacturers can operate on a levelled playing field in the market. Such an approach does not consider the fact that China has been providing consistent and material support to their solar industry over the last twenty years. The analysis of this report was based on the median bottom-up cost estimates for production presented in Section 3 of this report and includes financing and cost of capital assumptions to calculate the levelised cost of production (LCOP) over a ten-year production period. The assumptions underlying the LCOP are detailed in Appendix B.[132] This includes the LCOP at each step over the value chain over a 10-year production period.

The shortlist of policy levers assessed is presented in Table 15, and discussed further in the following sections to formulate conclusions that can guide urgent policy development in Australia. Analysis of policies which were not carried forward to the recommendations are included in Appendix D and E.

Table 15: Short list of policy options for detailed assessment

Barrier to industry development	Policy lever	Sub-section reference
Uncertain investment environment	Enabling policy levers	5.2
Uncertainty on the intent of governments to support solar PV manufacturing	Announcement/recognition of solar PV manufacturing as a strategic government priority	5.2.1

[132] Please note that the model is illustrative and has particular limitations, including assumptions regarding the facility size, representative location within Australia, and today's costs (rather than forecasting future facility costs based on learning rates). The results should therefore not be considered as accurate representations of the real cost of manufacturing over the life of a facility but provide a useful benchmark to understand the effectiveness of each policy lever on the cost of manufacturing, and what the associated cost to government might be.

Uncertainty on permitting and approval timelines	Streamlined permitting and approvals within a transparent framework.	5.2.2
Uncertainty on foreign investment process and outcomes	Foreign investment guidelines.	5.2.3
Limited access to skilled labour	Targeted visas and reskilling support.	5.2.4
Demand uncertainty	Demand-side policy levers	5.3
Demand uncertainty for locally produced solar PV products	Government procurement guarantees	0
	Local content incentives and requirements	0
	Import standards*	refer to Appendix
	Anti-dumping regulation*	refer to Appendix
Demand uncertainty for Australian exports	International partnerships	5.3.2
Domestic solar module demand uncertainty	Facilitating solar PV development and module installation	5.3.3
Cost premium	Supply-side policy levers	5.4
High ongoing operational costs (OPEX)	Production-linked support	5.4.1
Limited access to low-cost capital	Concessional finance	5.4.2
High upfront capital costs (CAPEX)	CAPEX support	5.4.3
High electricity costs and future electricity price uncertainty	Electricity price guarantees	5.4.4
High ongoing operational costs (OPEX)	Temporary tax reductions*	refer to Appendix

*Note: these policies were assessed, however are not part of the final recommendations for government to focus on, as they are not appropriate at this stage for timely industry building. However, they can be valuable to consider by government in specific cases or in the longer term. Refer to Appendix D and E for the detailed analysis.

5.2. Enabling Policy Levers: Supporting a Successful Manufacturing Environment:

Extensive stakeholder engagement identified that key barriers at the project development stage need to be addressed for successful industry establishment, and for projects to reach final investment decision (FID). Without this enabling support, direct or indirect financial support will likely be ineffective at attracting private investment to Australia. Challenges include uncertainty related to approvals and permitting outcomes for manufacturing facilities, uncertainty on projects including foreign investment or international partnership possibilities and sufficient access to appropriately skilled labour. Enabling policies should be rolled out in the short term, to create a successful environment for solar PV manufacturing to develop.

5.2.1. Priorities: Solar PV Manufacturing as a Strategic Priority Industry

Industry stakeholders have repeatedly identified the need for certainty in the intention of governments (federal, states and territories) to support the solar PV manufacturing sector as a strategic priority over the long-term.

Australia is competing on a global stage to attract international solar PV manufacturing capability and private investment to Australia. In the current environment, solar PV manufacturing projects in Australia are unlikely to reach final investment decision (FID), due to cost premium of manufacturing in Australia and associated high hurdle rates.

Australian governments have signalled their intention to support net-zero technology manufacturing, however explicit support for the solar PV industry has not been announced to date. The recently announced National Reconstruction Fund (NRF) will include up to 3bn AUD for 'renewables and low emissions technologies'. However, it is unclear whether and how much of the funding could be allocated to solar PV manufacturing. In addition, several Australian states have formal statements and strategies to support advanced manufacturing *(refer to existing supportive policies in Appendix H)*. However, Queensland's Roadmap on Advanced Manufacturing is the only State that highlights solar components as a priority.

Other jurisdictions, such as the US, Canada, EU and India have clearly identified solar PV manufacturing as a priority industry and developed supporting policy accordingly. For example, the EU Net Zero Industry Act (NZIA) states that by 2030, the European Union should meet 40% of its annual deployment needs in strategic net-zero technologies (which include solar PV) with domestic manufacturing capacity[133].

Clear and decisive signalling from the government is needed, including explicitly identifying solar PV manufacturing as a strategic priority and incorporating it into funding mandates and strategies. Similar to the EU NZIA, this could be facilitated through definition of a national target for solar PV manufacturing, e.g., 20% of annual demand (approx. 1 GW). This target should then be reflected in the programming of support.

5.2.2. Permits: Streamlined Permitting and Approvals

Industry stakeholders have identified significant project development uncertainty, relating to timing, complexity and outcome of the permitting and approvals process.

Manufacturing facilities in Australia need to comply with federal legislation (which includes obtaining environmental approvals, native title approvals, customs clearance for imported products, etc.) as well as state/territory requirements (such as receiving development approval for future facilities).

Streamlining initiatives for permitting and approvals exist. On a federal level, projects that are of strategic significance to Australia with an estimated investment of more than 50m AUD can obtain additional support from the Major Projects Facilitation Agency (MPFA). On a state level, different

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[133] European Commission, https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en, viewed 24 Oct 2023.

Australian states and territories have processes in place to accelerate and streamline approvals for "major" or "state significant" projects.[134]

However, despite these streamlining initiatives, stakeholders highlighted that industry faces significant investment uncertainty due to the lack of certainty on industry-specific requirements without precedence in Australia, process complexities through interaction of federal and State approvals, as well as lengthy and unknown processing timeframes. This is particularly relevant for the large-scale energy and chemical-intensive facilities required at the poly-Si, ingot/wafer and cell manufacturing steps. For example, indicative approval timelines of 3-5 years are considered likely for a poly-Si facility which, in addition to longer construction timelines, would significantly impact speed to market, allowing others who can move faster to obtain market share, which in-turn makes Australia's market entry more difficult. Speed and scale are critically important if Australia is to enter the PV supply chain in a meaningful way.

Clear upfront guidance and a streamlined process for permitting and approvals is needed to increase investment certainty for prospective solar PV manufacturers in Australia. Similar to the EU NZIA *(see case study below)*, this can be achieved through a range of streamlining processes, including:

- Provision of a targeted pre-approval engagement service for solar PV manufacturing facilities to enhance clarity and certainty on application requirements, timelines and outcomes
- Commitment to accelerated processing timeframes through increased staffing of government agencies, or maximum application processing timeframes
- Increased coordination between government agencies to ensure timely delivery and outcomes of approvals
- Publication of sector-specific guidance for emerging priority sectors such as solar PV manufacturing
- Streamlining of community engagement and feedback periods

Additionally, government can play a role in ensuring environmental planning is achieved at a place-based instead of project-based level in strategic industrial hubs. For example, this could include coordination of industrial hub-wide environmental baselining to accelerate project specific Environment Protection and Biodiversity Conservation Act (EPBC) approvals. This lever would significantly streamline the approval process for a facility in terms of both costs (e.g., number of studies to execute) and timelines, while providing strategic incentives for facilities to locate in priority regions for development.

[134] Stakeholders have indicated that the Coordinator General process in Queensland is the most streamlined approval process to ensure projects can be developed in a timely manner, through provision of whole-of government coordination for the impact assessment.

Case Study: EU – Net Zero Industry Act (NZIA)[135,136]

Through the Net Zero Industry Act, the European Union aims to attract investment and create better conditions and market access for an EU clean-tech sector at pace with global trends.

The key target under the NZIA is for its overall strategic net-zero technologies manufacturing capacity to approach or reach at least 40% of annual deployment needs by 2030. The EU will identify priority projects essential for reinforcing the resilience and competitiveness of the EU net-zero industry.

To achieve this, the EU will aim to provide a simplified regulatory framework to cut red tape and accelerate permitting. Especially **strategic projects will benefit from even faster permitting**, to increase planning and investment certainty. More specifically, the following time limits on permit granting will be introduced:

- **Strategic** net-zero projects:
- 9 months, for yearly manufacturing capacity of less than 1 GW
- 12 months, for yearly manufacturing capacity of more than 1 GW
- Net-zero technology manufacturing projects:
- 12 months, for yearly manufacturing capacity of less than 1 GW
- 18 months, for yearly manufacturing capacity of more than 1 GW

To achieve this, "**one-stop-shops**" will be created (= sole point of contact for investors & industrial stakeholders during the administrative process), and additional staff will be hired to **strengthen administrative capacity**. Additionally, **regulatory sand boxes** will be set up. A regulatory sandbox is a tool allowing businesses to explore and experiment with new and innovative products, services or businesses under a regulator's supervision.

5.2.3. Partners: Foreign Investment Guidelines

For the steps of the solar supply chain for which Australia does not currently possess the expertise, a joint venture with an international firm with the appropriate technology, IP knowledge and manufacturing expertise is the most plausible pathway to develop capacity in Australia in a timely manner. International operating partners will likely be required to provide technology IP, equipment, setup, and initial training of the domestic workforce. In particular, Australia's solid and longstanding relationship with China in the solar sector could be a defining factor in the success of Australian manufacturing. Over the past few decades, both countries have jointly developed substantial technological

[135] European Commission, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan/net-zero-industry-act_en, viewed 24 Oct 2023.
[136] European Commission, https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_1666, viewed 24 Oct 2023.

advances.[137] The continuous growth of know-how and the ever-evolving technological improvements adopted by the extensive Chinese solar industry are likely to be vital in helping Australia stay competitive in the years ahead.

Generally, however, stakeholders (national and international) have indicated high uncertainty around foreign investment approvals by the Foreign Investment Review Board (FIRB), with regards to both timing and outcome.

Early engagement between industry and government on the feasibility of international partnerships will be key for success in stablishing domestic solar PV capability. Government should provide more certainty on international partnerships and JVs by recognising solar PV manufacturing as a strategic priority industry for development. Key actions may include:

- Provision of upfront guidance on the role that international companies might play in this sector
- Announcement of industry-specific acceptable thresholds for JVs and partnerships

5.2.4. People: Targeted Visas and Reskilling Support

Prospective solar PV manufacturers anticipate challenges with regards to attracting and retaining a properly skilled workforce in Australia, due to skilled labour shortages, a lack of specialised manufacturing training, a lack of workers with direct experience in solar PV manufacturing and a lack of sufficiently attractive visas. Further detail on barriers to accessing an appropriately skilled workforce are outlined in Table 16 below.

Table 16: Barriers faced by industry with regards to workers

Skilled labour shortage	Australia currently has a severe shortage of skills in the clean energy industry. More specifically, 9 out of 12 roles the Australian Industry Energy Transitions Initiative believes key to the energy transition, are currently in shortage in Australia (including engineers, plant operators, construction labourers and electricians).[138] A lack of access to skilled labour will affect Australia's ability to realise the full potential and benefit that domestic solar PV manufacturing can provide. Moreover, solar PV manufacturing would be competing for some of these workers both with other high wage-paying industries in Australia (such as mining, other green tech emerging industries, etc.) as well as competitors on a global scale. These shortages will likely drive wages upwards. In addition, solar PV manufacturing would likely be located in regional areas due to the proximity of necessary infrastructure, land and cost considerations. However, skilled workers usually live in major population centres. This mismatch implies solar PV

[137] Green, "How did solar cells get so cheap?", *Joule*, 20 March 2019.
[138] ARENA & Accenture, "Australian Industry Energy Transitions Initiative", viewed 15th May 2023.

	manufacturing will have to compete with jobs and projects that are located in metropolitan areas and do not involve travel.[139] Moreover, workers may be disincentivised from moving to regional and industrial areas for concerns relating to affordable housing, services such as schools and hospitals, amenities such as public transport and social considerations
Lack of training capacity	Many jobs in the clean energy sector are highly specialised and require complex skillsets. Australia currently lacks labour with expertise in specialist manufacturing roles. To address the existing skills shortage within Australia, it will be necessary for workers in roles utilising similar skills to be retrained in areas that solar manufacturing can take advantage of. However, due to the lack of existing industry, specialised manufacturing skills are not widely taught at Australian universities or vocational training institutions.
Lack of workers with direct solar manufacturing expertise	Australia lacks workers with direct solar manufacturing experience, which currently can only be obtained overseas. Foreign skilled workers will need to come to Australia in the first stages of industry development to set-up, operate and train the domestic workforce, thereby enabling the creation of jobs for Australians. Alternatively, Australian workers seeking to gain manufacturing experience would need access to state-of-the art international manufacturing facilities under cooperative skills and training programs with trade partners.
Sufficiently attractive visa options for highly skilled foreign workers	Attracting and retaining highly skilled international PV manufacturing workers is perceived as a barrier for companies considering a joint venture with an international company in Australia. While different visa programs exist in Australia, the system is complex and stakeholders have emphasised the need for appealing visa options, with accelerated processing timeframes and options for permanent residency. Prospective investors have highlighted international workers would need clarity on their prospects of being able to work and live in Australia permanently.

To prepare its workforce for growing green manufacturing, the EU, grappling with some of the same challenges as Australia, is taking policy measures. It will establish targeted Net-Zero Academies to up-skill and re-skill workers, assess how skilled immigration can fill roles in priority sectors, as well as

[139] UTS, https://www.uts.edu.au/news/social-justice-sustainability/transition-needs-thousands-more-skilled-workers-fast, viewed 15th May 2023.

assess levers to incentivise public and private funding to develop the appropriate skills *(see case study below)*.

Case Study: EU – Enhancing worker skills for green industry

Europe recognises that a '***sizeable skilled workforce*' is necessary** to strengthen net-zero technology manufacturing capacity. Particularly, where large growth is being seen in new technologies, **skills and skilled workers will need to accompany that growth**. The Net-Zero Industry Act will set up targeted training through establishing **Net-Zero Academies** which will assist in promoting **up-skilling and re-skilling programmes** in particular industries. Academies will focus on single net-zero technologies, and each aim to train **100,000 learners within its first 3 years**.

The Academies will be supported and overseen by the Net-Zero Europe Platform, with the ultimate aim of **creating quality jobs** through providing training and education on the **technologies of the future**.

It aims to do this by combining a '**Skills-first**' approach with traditional approaches based on qualification. It also wants to assess how EU labour markets in priority sectors can be accessed by **third country nationals**. Lastly, it will assess how **public and private funding** can be incentivised and aligned to develop the skills that are necessary in a transitioning economy.

To guarantee solar PV manufacturers have access to the right skill set to establish capacity in Australia, governments should ensure that streamlined visa pathways exist in the government's renewed Migration Strategy[140] for solar PV manufacturing workers in the near term, while developing specific worker reskilling support and training programs in parallel.

The skilled occupation list specifies occupations that the Australian government has deemed as important for Australia's economy, with foreigners holding these qualifications eligible to apply for particular visas to live and work in Australia. Addition of trades in shortage for solar PV manufacturing to the priority migration skilled occupation list, along with a commitment to a set number and processing timeline of streamlined skilled worker permits or visas to support solar PV manufacturing facilities would give certainty on timelines to investors. These could be linked to domestic workforce training requirements for international partner companies.

Governments can play a role in promoting collaboration between industry and academic institutions to set-up the relevant PV manufacturing training courses and apprenticeships. Some of these training programmes for workers in solar PV manufacturing can be subsidised by government to reduce costs

[140] Home Affairs, https://immi.homeaffairs.gov.au/what-we-do/migration-strategy/the-migration-strategy, viewed 12th October 2023.

and ensure competitiveness. Both could be achieved through the Government's *New Energy Apprenticeships Program* and *New Energy Skills Program.*[141]

International exchange programs with solar manufacturing countries could be set up to build on Australia's strong track record in cell technology development. For example, countries with existing manufacturing expertise such as India could send undergraduate and postgraduate students to Australia for PV engineering courses, while Australia could send engineering professionals or other trades to India for onsite manufacturing training.

Lastly, working in solar PV manufacturing can be made more attractive to both local and international workers through additional industrial workforce incentives, for example, by linking industrial clusters with affordable housing, affordable quality childcare and schools, public transport and other amenities.

5.3. Demand-side Policy Levers: Overcoming Demand Uncertainty

Offtake or demand certainty is critical to providing longer-term investment certainty for new or developing industries, due to competition with established international players that benefit from economies of scale and an ability to adjust profit margins in response to new market entrants. Australian governments can play a role to overcome investment uncertainty by implementing policies that stimulate demand for domestic solar PV products.

The type of support required should evolve over time, in line with the scale and maturity of industry development in Australia.

- **Levers encouraging demand for locally produced products (domestic demand incentives)** such as government procurement or local content premiums are critical in early to medium stage industry development to encourage offtake of domestic products without penalizing consumers or increasing the cost of products.
- **Levers creating a level-playing field for the domestic market (international supply measures)** can play a role during and after the establishment of a domestic industry, to protect domestic solar PV manufacturing in Australia in the long-term. They can also be adopted to limit certain practices (such as modern slavery or unsustainable manufacturing practices). However, these policy measures have a higher risk of decreased economic efficiencies, retaliatory action and trade disputes and are therefore not directly recommended in this study. Refer to Appendix D for the assessment of import standards and anti-dumping regulation.

Additionally, indirect demand levers such as international partnerships can facilitate demand for Australian export-focussed products, whilst removing barriers to large-scale PV deployment or mandating solar PV installation can create more certainty on size and timing of demand for solar PV products in general.

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[141] Alicia Payne MP, https://aliciapayne.com.au/policy-folder/labor-s-new-energy-apprenticeships/, viewed 3rd October 2023.

5.3.1. Levers Encouraging Demand for Locally Produced Products

Although local and international stakeholders have indicated that there is an appetite for Australian-made, environmental, social and governance (ESG) conscious and low carbon solar PV products, there is high uncertainty around sustained market demand if the products are sold at a premium price compared to overseas imports. Assuming government support to overcome the cost gap (refer to Section 4), this could still occur if established international players deploy market tactics to undercut an Australian industry. Willingness to pay a premium is unlikely in the absence of mandated local content/low carbon/supply chain transparency requirements or financial incentives. To attract investment for solar PV manufacturing capability, guaranteed offtake of Australian-made products is therefore important in the early years.

Government procurement guarantees

Australian governments can leverage their purchasing power and provide offtake certainty through guaranteed government procurement. Some Australian governments already have specific strategies in place for solar PV installations on public buildings and provide funding accordingly. For example, in 2020, the Victorian Government announced the 9.2m AUD Solar on Public Buildings program, aimed at installing solar systems on buildings on eligible types of Crown land such as community halls.[142] Similarly, in 2023, the NSW Government invested 4.1m AUD as part of its Rooftop Solar Program to install rooftop solar on 22 courthouses, estimated to generate up to 2,400 MWh of electricity every year.[143] Government strategies similar to these could include commitments to source solar panels locally.

While government local procurement by itself is not of a large enough scale to ensure demand certainty, it would guarantee a certain offtake and provide an important signal to industry of Australian governments' commitment to support solar PV manufacturing development. For example, in the US *(see case study below)*, the current Biden-Harris administration has declared federal procurement to support US-based manufacturing, a priority of their presidential term and industrial strategy. Critics of the policy have argued that it increases costs for taxpayers, and risks reducing the quality of products as well as production efficiency. However, the US government considers the enhancement of national security and increased resilience for critical goods of greater importance, especially after having experienced critical disruptions during the COVID-19 global pandemic. Measures can include increasing the domestic content threshold for government procured projects and products, as well as applying enhanced price preferences.

Similarly, Federal and State governments can play a role as an early adopter of Australian-made solar panels across public buildings (such as hospitals, schools, public housing, police stations, etc.) and be ambitious on the roll-out of solar on public assets. Governments should consider preferentially procuring PV modules with higher domestic content levels. Australian governments can also push for

[142] Department of Energy, Environment and Climate Action, https://www.forestsandreserves.vic.gov.au/land-management/managing-crown-land/solar-on-public-buildings-program, viewed 24 Oct 2023.
[143] NSW Government, https://dcj.nsw.gov.au/news-and-media/media-releases-archive/2023/nsw-courthouses-solar-power-into-greener-future.html, viewed 24 Oct 2023.

social and environmental objectives by linking procurement guarantees with social and environmental standards.

Case Study: Buy American Act[144]

The Buy American Act is a US policy mandating the use of domestically manufactured products in certain projects by federal agencies and contractors. To further ensure American taxpayer money would flow back into the investment of American jobs and manufacturing, the Biden administration proposed the following changes to the Buy American Act:

- Increasing the domestic content threshold from 55% to 60%, gradually increasing to 75%
- Applying new price preferences for critical goods
- Enhancing transparency and accountability through reporting requirements of critical goods

Local content incentives and requirements

Offtake of Australian-made products can be boosted through local content measures. Local content measures can take the form of incentives, such as a bonus payment for local content use or preferential selection in tender processes, as well as requirements which mandate the use of local content.

In Australia, local content requirements are already included in some State-based tender processes for renewable energy developments, such as the VRET auctions in Victoria and the LTESA tender assessment in NSW.[145, 146] However, stakeholder feedback has indicated that a shortage or lack of existing Australian made products in these sectors means that the local content requirements are not effectively implemented or enforced. In addition, insights from stakeholders suggest that cost/price of tenders has been scored more highly than local content requirements, resulting in lack of effectiveness of the requirement in some cases.

A variety of local content incentives have been effective overseas, to support demand for locally produced solar PV products. Türkiye has a long history of using local content incentives to support domestic solar PV manufacturing and has been successful in setting up domestic capacity through these policy measures *(see case study below)*.

144 White House, https://www.whitehouse.gov/briefing-room/statements-releases/2021/07/28/fact-sheet-biden-harris-administration-issues-proposed-buy-american-rule-advancing-the-presidents-commitment-to-ensuring-the-future-of-america-is-made-in-america-by-all-of-americas/, viewed 24 Oct 2023.

145 AEMO, https://aemoservices.com.au/-/media/services/files/tender-round-3/tender-round-3-tender-guidelines.pdf?la=en&hash=B5BEFE3961ADF5EC81605EB6ACE28C48, viewed 24 Oct 2023.

146 Department of Energy, Environment and Climate Action, https://www.energy.vic.gov.au/renewable-energy/victorian-renewable-energy-and-storage-targets/victorian-renewable-energy-target-auction-vret2#:~:text=VRET2%20will%20help%20meet%20Victoria%27s,energy%20storage%20capacity%20by%202030, viewed 15 June 2023.

Case Study: Türkiye – Additional feed-in tariff[147]

Türkiye built up its solar PV manufacturing industry from being almost non-existent to producing approximately 7GW worth of modules in 2022. It initially focused on demand policies, and then supported supply. Initially, Türkiye offered premiums on top of existing feed-in-tariffs for 10 years if non-mandatory local content requirements were complied with. Module assembly capacity grew as modules assembled with locally produced glass and aluminium frames were eligible for the bonus.

Most recently, Turkish PV systems that are installed between July 1 2021 and December 31 2030 will receive a 10-year feed-in tariff of TRY 1.06 (0.0545 USD)/kWh (YEKDEM). Solar projects that include **Turkish PV components** will receive **an additional 5-year tariff** of TRY 0.2880 (0.015 USD)/kWh.

In the US, renewable energy developers can obtain an additional tax credit under the Inflation Reduction Act (IRA) when certain domestic content requirements are met. The IRA has significantly boosted investment since its announcement, with 270bn USD of capital investment announced for clean energy projects, and over 22bn USD in manufacturing investment.[148] The effect of the local content bonus has yet to be determined. However, for solar manufacturing specifically, the impact of the domestic content requirements may be limited given the lack of mature domestic solar PV supply chains in the US, unlike industries which can utilise domestic content requirements advantageously, like wind.[149]

Importantly, the domestic content definitions for solar PV in the US begin at the cell step of the value chain, meaning that domestically produced poly-Si and ingot/wafer would not benefit from the current domestic content bonuses.

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[147] PV Magazine, https://www.pv-magazine.com/2023/05/02/turkey-introduces-10-year-fit-for-solar-other-renewables/#:~:text=The%20Turkish%20authorities%20have%20set,%2C%20and%20December%2031%2C%202030, viewed 24 Oct 2023.

[148] American Clean Power, "Clean Energy Investing in America", August 2023.

[149] Wood Mackenzie, https://www.woodmac.com/news/opinion/ira-impact-renewables-project-planning/, viewed 24 Oct 2023.

Case Study: US – Additional tax credit in Inflation Reduction Act

Under the Inflation Reduction Act, clean energy producers based in the US can **increase the tax or production credit** granted under applicable programs **by 10%,** if a facility meets certain domestic content requirements for steel, iron and manufactured products.

Definition of domestic content: "Any steel, iron or manufactured product must be produced in the US. This condition is satisfied if all the primary components are manufactured in the US. If this requirement is not met, alternatively, if 40-55% of the total combined costs of all manufactured products (depending on the year construction commences) are attributable to components mined/produced/manufactured in the US, then this condition will be taken to be met."

In Australia, governments can leverage existing structures to implement local content requirements. State government tenders and Renewable Energy Zones (REZ) selection processes, like the Victorian VRET and New South Wales LTESA tenders, can specifically include domestic solar PV requirements once industry has developed. However, while industry is being established, local content measures can take the form of a 'bonus payment' or a preferential assessment criterion in tenders instead of a requirement.

Additionally in the short term, a local content bonus can be provided for solar PV installers, similar to the US and Türkiye. In Australia, this could be implemented through payment of a 'bonus credit' for installation of domestically produced panels, or through a payment mechanism for electricity generation. For example, through an extension of the Renewable Energy Target (RET) or a RET-like mechanism, the Clean Energy Regulator (CER) could opt to pay a premium (fixed price or percentage) to the certificate generator for green electricity produced with locally manufactured panels.

Regardless of policy lever implemented, careful definition of local content will be needed, to prevent industry exploitation of loopholes and unintended outcomes. The definition will need to be flexible to extend to upstream value chain segments if and when those capabilities develop domestically, as well as consideration of whether certain contract manufacturing arrangements with third-country partners would qualify to fill gaps in the Australian domestic capability. Similar to the case of Türkiye, the scope can also include adjacent industries such as Australian glass and Australian aluminium, thereby indirectly supporting domestic glass and aluminium production by recognising these inputs as local content in module assembly. The scope could be further broadened to include locally produced batteries, wind components and other green energy products, thereby supporting the efforts made in other clean energy supply chains.

Importantly, implementation of a local content requirement should only occur in combination with supply-side support, to avoid price increases to consumers and slowing deployment of renewables (refer to Policy Principle 1: *Policy should be designed to not severely impact the cost/speed of the Australian energy transition*).

5.3.2. International Partnerships

Australian solar PV manufacturers targeting export markets would benefit from government support in establishing strategic partnerships with other jurisdictions, to facilitate demand for Australian solar PV exports.

As outlined in Section 6, an Australian poly-Si and ingot/wafer facility may have the potential to service an export market in the EU and US, due to several factors including shortfalls of domestic capability building in those markets compared to cells and modules, existing trade restrictions on Chinese poly-Si in the US, and overall higher geographic concentration and hence supply chain vulnerability at the ingot/wafer step. Demand for Australian poly-Si and ingot/wafers will therefore largely be dependent on which export market is targeted and trade dynamics.

In addition, developing targeted partnerships with third countries presents an opportunity to set up contract manufacturing to fill value chain gaps and develop a fully diversified supply chain where Australia does not develop domestic capability. This could be the case e.g., for cell manufacturing, at least in the short term.

The Australian government is already actively setting up strategic partnerships with other jurisdictions to build up shared supply chains for green technologies, such as the Critical Minerals and Clean Energy Transformation Compact with US *(see case study)* or the India-Australia Joint Solar Taskforce. Government can play a role in addressing the demand uncertainty for potential Australian solar PV exports by facilitating trade agreements and setting up formal supply chain partnerships for solar PV components in particular.

Case Study: AU-US Climate, Critical Minerals and Clean Energy Transformation Compact

During the G7 in Japan in May 2023, Australia and the US announced the Climate, Critical Minerals and Clean Energy Transformation Compact. It is a partnership focused on aligning and accelerating the development of critical minerals and clean energy industries in the two countries.

The details are to be announced by the end of 2023; they aim to:

- expand and diversify clean energy supply chains, focusing on solar, wind, storage, and hydrogen technologies
- use domestic financial instruments and incentives to promote integration of responsible clean energy supply chains and attract investors
- work together to support clean energy transformation in the Indo-Pacific region, particularly through collaboration with developing countries
- ensure a responsible and stable supply of critical minerals for the global energy transformation, addressing market risks and distortions
- prioritise development of emerging battery technologies, including coordination on standards, regulations, tracing, and recyclability
- foster clean hydrogen industries through research, incentives, and public-private partnerships

5.3.3. Remove Barriers to Domestic Utility-scale Solar PV Deployment

While there is a large pipeline of renewable projects in Australia, developers currently face numerous barriers and difficulties in project development, resulting in deployment rates which are far off track to meet Australia's target of 82% renewable energy by 2030. Despite the current Australian governments' support for the energy transition, the Clean Energy Council reported the slowest pace of final investment approvals for new wind and solar farms in six years in August 2023. This may undermine the development of an Australian PV module manufacturing industry, through domestic offtake and demand uncertainty for manufacturers.

Barriers to deployment include challenges in the grid connection process and technical requirements, delays and difficulties in the permitting and environmental approvals process, as well as opposition from local communities to transmission infrastructure and large-scale solar and wind farms. To address these challenges, the Australian government has, amongst other measures, committed 20bn AUD in low-cost finance to modernise Australia's electricity grids through "Rewiring the Nation". However currently, the costs of these grid connection and approval processes, as well as costs of delays and project adjustments, is leading to a lack of projects reaching final development.

The Renewable Energy Target (RET) has been a highly successful model in Australia to incentivise both the development of large-scale solar farms as well as small scale and residential rooftop systems. The RET is planned to end in 2030, however industry has called for an extension of the scheme to accelerate and increase investment in renewables, as there is a current policy void beyond 2030.

Policies mandating the installation of solar PV are increasingly being adopted around the world, especially in Europe, where in some jurisdictions subsidy policies such as feed-in tariffs are being phased out and replaced with mandates.

Case Study: Mandates for solar PV installations

- In Flanders, Belgium, owners or leaseholders of buildings using more than 1 GWh of annual electricity will be obliged to install solar panels. A minimum capacity of solar installed per square metre of roof surface applies from 2025 onwards, increasing in 2030 and 2035. The rule applies to government buildings consuming more than 500 MWh of electricity as well.
- In France, it is now compulsory to install PV systems at parking lots of more than 1,500 square metres.
- The European Commission has proposed a solar rooftop requirement for commercial and public buildings from 2027, and for new residential buildings from 2029.
- California has a mandate for solar PV to be equipped on all new buildings from 2020 onwards.

To ensure solar module demand certainty for a potential solar PV manufacturing supply chain, Australian governments should prioritise actions to address barriers to solar PV deployment.

While this is a complex and multi-faceted challenge, government support should continue to prioritise investments in strategic grid infrastructure to support manufacturing (e.g., linking grid infrastructure to new production centres, facilitating and coordinating the planning of network investments, etc.) as well as streamlining the approvals process without undermining social and environmental concerns. In addition, increased support for labour shortages in the installation stage, such as electricians and solar installers, are critical.

In particular, Australian governments should provide greater investment certainty by clarifying the long-term policy mechanism void beyond 2030. Adoption of a similar mechanism to the RET would provide certainty and incentives to utility-scale PV developers as well as individuals and businesses to install solar PV.

5.4. Supply-side Policy Levers: Bridging the Cost Gap

Supply-side policy levers include direct or indirect financial support to bridge the cost gap to comparable imported products. Supply-side policies will be key to ensuring that Australian facilities can remain cost competitive with other economies, many of which are providing substantial financial incentives for domestic manufacturing.

- **Upfront capital support -** incentivises construction, and is often preferred by industry, especially at steps of the value chain that have high upfront capital costs, e.g., poly-Si, due to the higher upfront time value of money. Upfront capital support also helps to overcome the access to capital barrier.
- **Ongoing operational support** – incentivises production, as companies must be operational and producing outputs to receive financial support. The longer-term nature of the support provides cost certainty for producers, while linking government spend to direct production results.

A combination of upfront capital and ongoing operational support can balance industry and government priorities.

The following sections analyse supply-side policy levers suggested by stakeholders to address different barriers. The assessment dives deeper into the challenges faced by solar PV manufacturers in Australia, mechanisms of the policy levers, lessons learnt from international case studies, risks and design considerations.

Additionally, quantitative analysis was completed to assess the impact of each policy lever on closing the cost gap to China, as well as estimating the associated cost to government. The analysis indicated that, while effective at addressing specific barriers such as high upfront capital costs and high electricity prices, capital grants and electricity price guarantees are not effective at fully closing the overarching production cost gap at each step of the value chain.

5.4.1. Production-linked Support

Overview

Stakeholders indicated the importance of ongoing operational support, to overcome the higher cost of production in Australia across each step of the value chain.

Under a production-linked policy support framework, manufacturers receive financial incentives, tax benefits, subsidies, or other forms of support based on the quantity or value of goods they produce or sell. Production credits allow for bridging the economic gap, while providing investment certainty to industry and financial institutions. The main characteristic of production-linked support is that it incentivises production over the duration of the policy.

Several major economies are shifting towards production-linked support, setting a new precedent in green industrial policy. Australia recently introduced production-linked support for renewable hydrogen, as part of the *Hydrogen Headstart* program. The design of production-linked support for

PV manufacturing can adapt aspects of this mechanism, including features such as competitive bidding, a support cap, upside sharing and funding reduction *(see case study for more details)*.

	Production Credit Case Study: Australia – Hydrogen Production Credit[150]
Overarching policy/strategy	The Hydrogen Headstart Program has the objectives of accelerating the development of Australia's hydrogen industry and producing renewable hydrogen at scale in Australia.
Support size	2.0bn AUD, at least 2 large-scale projects will be supported. The size of the credit is decided through a competitive bidding process for Australian-based projects.
Proposed Start/Duration	Program was announced in May 2023. Expressions of interest opened mid-October. Successful projects will receive a production credit over a period of 10 years, with funding available from financial year 2026-27.
Mechanism	Funding recipients will obtain a "Hydrogen Production Credit" (HPC) for each kg of renewable hydrogen produced and have to demonstrate in their application process a HPC value reflective of the difference between the expected sales price and their production costs. Expected output volumes over the 10-year period need to be specified in the application and are a basis for maximum support that a facility can receive. A mechanism for upside sharing or funding reduction over time is included.
Considerations	Eligibility requirements included: Projects must be a new deployment of electrolysis/renewable hydrogen production facilities with a minimum of 50 MW electrolysis deployment The hydrogen production must be renewable hydrogen and be 100% powered with renewable electricity (behind the meter renewables, Guarantees of Origin or Power Purchase Agreements). Hydrogen produced from using coal gasification or steam methane reforming coupled with carbon capture and storage will not be eligible. Applications must include details on the proposed offtake, current level of discussions and a summary of the key terms and conditions.

	Applications must include a commercialisation pathway (cost reduction pathway) analysis. The extent of using local supply chains, engagement/consultation/benefits sharing with First Nations communities, and the number of jobs and training created are criteria in the assessment.
Impact	Although the beneficiaries of the program support have yet to be selected, industry has welcomed the support as a positive step towards scaling up renewable hydrogen in Australia.

The US Inflation Reduction Act *(see case study)* offers uncapped support, accessible to any US-based manufacturer, which makes it very attractive to industry and has led to an unprecedented boom of manufacturing announcements in the US. However, it has also sparked concerns among governments around the world that companies might relocate to the US. The credits are not a direct payment but can be offset against federal income taxes, a mechanism that is not common in Australia, but well-known amongst companies in the US. The impact of the IRA is significant, whereby between August 2022, when the IRA was passed, and August 2023, 83 new clean energy manufacturing facilities or expansions had been announced, with 52 relating to solar manufacturing. This represents over 270bn USD of announced capital investment for clean energy projects, and over 22bn USD in manufacturing investment.[151]

	Production Credit Case Study: US – Advanced Manufacturing Production Tax Credit (45X MPTC) in the IRA[152]
Overarching policy/strategy	The US Inflation Reduction Act (IRA) has the objective of curbing greenhouse gas emissions and reducing the cost of energy by investing in domestic green energy production
Support size for PV	Credit value: 3 USD/kg poly-Si, 12 USD/m^2 wafer, 0.04 USD/W cells, 0.07 USD/W module The support a taxpayer can receive is **uncapped.**
Start/Duration	Credits are available from 1 January **2023** and **gradually phased out between 2030 and 2032**, with no phase out for critical minerals. More specifically, from

[150] ARENA, https://arena.gov.au/assets/2023/10/Hydrogen-Headstart-Guidelines.pdf, viewed 24 Oct 2023.
[151] American Clean Power, "Clean Energy Investing in America", August 2023.
[152] US Department of Energy, https://www.energy.gov/eere/solar/federal-tax-credits-solar-manufacturers, viewed 24 Oct 2023.

	2030 onwards companies will receive 75% of the full unit credit, in 2031 50%, in 2032 25% and the credit ends from 2033 onwards.
Eligibility	To be eligible for the credit, production should take place in the United States or United States possession. There is no cap on the number of companies that can apply for credits.
Mechanism	A credit is obtained for each solar component produced by the taxpayer and sold during the taxable year. The **credit can be offset against federal corporate income taxes** imposed on the taxpayer, for any taxable year, for a total value that is equal to the sum of the credit amounts.
Considerations	Tax credits previously faced the criticism that companies must be profitable to reap the benefits of the mechanism. The IRA provides an answer to this challenge by making the production credits **transferable**: the taxpayer can sell all or a portion of its credits to another eligible taxpayer to receive a payment in cash. **On the other hand**, the manufacturer can obtain a **direct payment** from IRS for the tax credits for the **first five years** they are claimed.
Impact	The US Inflation Reduction Act support has been widely welcomed by industry, leading to a **boom in domestic manufacturing announcements:** by March 2023, this included: 47GW of annual solar module capacity, 16 GW+ of cell capacity, 16 GW+ of ingots and wafers, ~9 GW of inverters, 20,000 Mt of annual domestic poly-Si capacity added to the current 40,000 Mt.
Critique	Important trade partners like the European Union and Canada have **raised concerns of unfair state aid**. Fearing their domestic manufacturers will leave the country or go out of business, the European Union and Canada have drafted policy in response to the IRA.

Like the US, India has implemented effective production-linked support to boost domestic solar PV manufacturing *(see case study)*. Australia can leverage different elements of the Production-Linked Incentive Scheme in its own policy design, such as the competitive bidding process and elements of local content and green electricity use, as well as recycling requirements. More specifically, like the proposed hydrogen production credit in Australia, the Indian production-linked incentive scheme uses a competitive bidding process to allocate funds and a cap on the total incentive amount. The scheme requires a minimum amount of integration across cells and modules. The incentive is higher the more efficient the module is, and the more local content is used in the manufacturing process. The latter can be replicated for Australia to support the domestic market. The scheme includes requirements for the recycling of solar waste as well as a minimum percentage of green electricity use.

	Production Credit Case Study: India – Production-linked incentive scheme (PLI)[153, 154]
Overarching policy/strategy	The production-linked incentive scheme in India has the objective of adding 65 GW of annual domestic solar PV manufacturing capacity of fully and partially integrated high efficiency modules with a goal of reducing India's reliance on imports.
Support size	The PLI includes 195bn INR (2.4bn USD) of funding. The second round (tranche II) has an emphasis on integrated manufacturing: • poly-Si, wafers, cells and modules or a fully integrated thin-film module plant (maximum bid: 10 GW, funding available: 12bn INR) • ingots and wafers, along with solar cells and modules (maximum bid: 6 GW, funding available: 4.5bn INR) • solar cells and modules (maximum bid: 6 GW maximum bid, funding available: 3bn INR) • The support is allocated through a bidding system, the maximum capacity granted is 50% of the bid capacity.
Start/Duration	Funding was made available in February 2021, and the amounts will be assigned for five years from the commissioning of the manufacturing site or five years from the scheduled commissioning date, depending on whichever is earlier.
Mechanism	The support is a direct payment linked to the production and sales of a manufacturer: the total amount a bidder can receive is the product of four components: the base PLI rate based on the module efficiency × the local value addition factor × tapering factor × yearly sales or maximum eligible capacity (whichever is less).
Considerations	Bidders can be a single company, or a joint venture/consortium Both green or brownfield sites can be used to set up manufacturing facilities, however the latter is only eligible for 50% of the PLI for greenfield sites. A minimum level of integration across the solar supply chain is required, as well as minimum 1 GW of capacity

[153] PVTech, https://www.pv-tech.org/india-releases-new-production-linked-incentive-scheme-guidelines-for-solar-manufacturers/, viewed 24 Oct 2023.
[154] Ministry of New and Renewable Energy, https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/08/2023080863.pdf, viewed 24 Oct 2023.

	Bidders have to comply with minimum values of module performance and local value addition, the higher these are, the better the score the bid receives Submissions should include estimated export figures and predicted job creation over the duration of the support, the proposed technology and plans for local value addition. Manufacturers will be obliged to set up facilities for the recovery and recycling of solar waste, along with adopting circular economy principles. Minimum 20% of the electricity consumption should be sourced from renewable energy.
Impact	To date, under tranche 2, ~40 GW of domestic module manufacturing has been allocated to 11 companies, with 7.4 GW due to be operational by October 2024, 16.8 GW by April 2025, and the balance by April 2026. This represented an outlay of ~1.7bnUSD in investment. Around one million direct and indirect solar jobs are expected to be created.

Quantitative Analysis

The quantitative analysis evaluates the size of support needed to be competitive with China and assesses the impact a policy lever has on closing the cost gap (refer to section 5.1. for the policy assessment methodology).

When applied to the Australian solar PV manufacturing context, quantitative assessment indicates a production credit can be sized to fully close the cost gap to the imported cost from China for all four value chain steps over a 10-year production period *(see Figure* 5-1*, Figure* 5-2*, Figure* 5-3*, Figure* 5-4*).* This would imply a subsidy equal to 9.30 USD/kg for poly-Si, 8.7 USD/m^2 for ingot/wafer, 5 USD/cW for cells and 3.4 USDc/W for modules in the absence of other financial support.

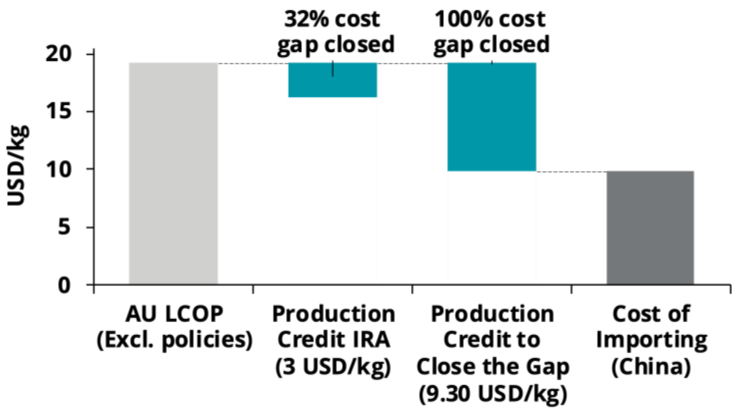


Figure 5-1: Impact of production credit for poly-Si

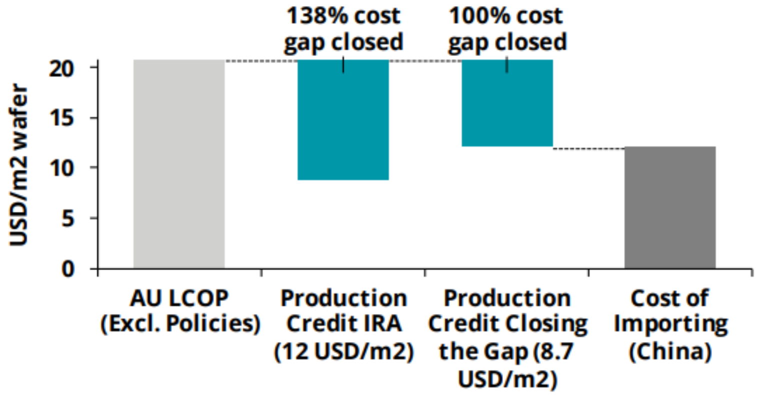


Figure 5-2: Impact of production credit for ingot/wafer

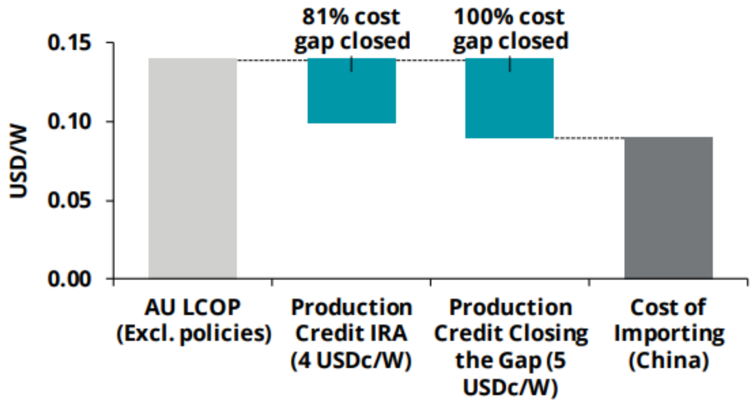


Figure 5-3: Impact of production credit for cells

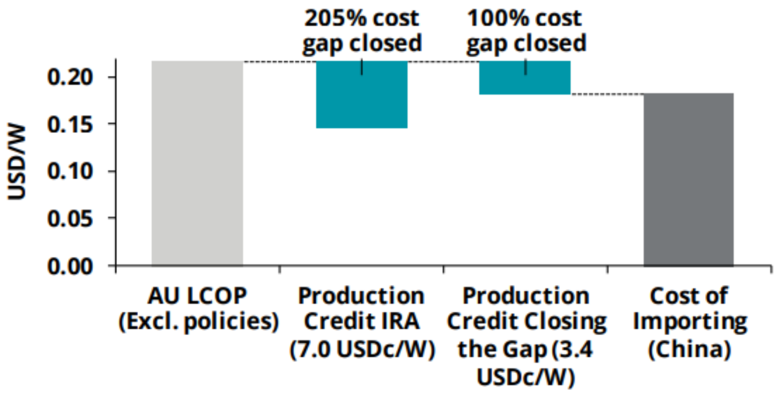


Figure 5-4: Impact of production credit for modules

The total cost to government to support a facility of minimum viable scale for a 10 year production period is presented in Table 17 below. The support required for a poly-Si facility is clearly an order of magnitude higher than the following value chain steps, due to the minimum viable facility scale of 10 GW/annum.

Table 17: Total support required to implement production-linked support, sized to close the cost gap[155]

	Size supported (per annum)	Total support required (discounted)	Annual support for 10 years of production (undiscounted)
Poly-Si	10 GW	~1.5bn USD ~(2.2bn AUD)	~232.6m USD (~330.1m AUD)
Ingot/wafer	1 GW	~228.0m USD (~323.6m AUD)	~34.7m USD (~49.2m AUD)
Cell	1 GW	~293.2m USD (~416.1m AUD)	~44.6m USD (~63.4m AUD)
Module	1 GW	~202.7m USD (~287.8m AUD)	~30.9m USD (~43.8m AUD)

Comparison with IRA:

The relative sizing of support required, compared to the IRA, varies across the supply chain, and provides an insight into potential supply chain steps that may be strategically developed to complement (rather than compete with) the US IRA:

- **Poly-Si:** The size of the suggested Australian subsidy is significantly higher than the IRA at 3 USD/kg. However, project announcements to date and stakeholder feedback have indicated the IRA is unlikely to be sufficient to stimulate significant investment in poly-Si, as support is comparatively lower than other steps of the value chain, and sunsetting of support from 2030 will likely leave insufficient time for a new poly-Si facility to access a large portion of support. This presents an opportunity for Australia to complement the IRA through development of an export-focussed industry in the longer term.
- **Ingot/wafer**: The estimated subsidy is approximately two thirds that of the IRA at 12 USD/m^2 wafer. Project announcements to date and stakeholder feedback have indicated that, despite the size of the production credit, the IRA is unlikely to stimulate significant investment in ingots/wafers due to limitations around accessing state-of-the-art Chinese IP and technology. This presents an opportunity for Australia to complement the IRA through development of an export-focussed industry.
- **Cell:** This estimated subsidy is approximately equivalent to, albeit slightly higher, than the IRA at 4 USDc/W. Project announcements to date in the US indicate that the IRA-sized support will be highly successful at developing a cell manufacturing industry in the US.
- **Module:** The estimated subsidy required is less than half that of the IRA at 7 USD/W. Project announcements to date in the US indicate that module capacity will exceed forecast domestic demand by a factor of three in response to the IRA policy support. While it is unlikely that all these projects will become operational, this indicates the sizing of the IRA may be too generous. Australia's increasing domestic market demand may therefore be an attractive incentive for industry, even with the lower subsidy proposed in this study.

[155] Exchange rate used for USD to AUD: 0.7045 USD/AUD (average of 2023/4 to 2026/7, Deloitte Access Economics, https://www.deloitte.com/au/en/about/press-room/business-outlook.html, viewed 24 Oct 2023). Minor discrepancies may exist due to rounding of the numbers.

Conclusion

Production-linked support is an effective mechanism for government to bridge the cost gap in the solar PV supply chain, catalyse industry growth and crowd-in private capital. A production credit is the only modelled policy lever that can be sized to fully close the cost gap for Australian manufacturers.

Setting up production-linked support comes with administrative complexities, such as establishing eligibility criteria, monitoring production levels and verifying compliance, and can therefore be resource-intensive. To address this concern, lessons can be learned from the government's experience with implementing the hydrogen production credit in the Hydrogen Headstart Program.

The mechanism, which would likely be implemented as a direct subsidy payment rather than a tax credit in Australia, requires significant investment but does not require a large upfront budget allocation from government. The main benefit of production credits for government is that they work on a payment-on-results basis and government does not provide upfront support to a company. Risks can be mitigated through the policy design, such as a support cap to provide government cost certainty, upside sharing or funding reduction features linked to increased market sales prices, eligibility requirements linked to key social and environmental objectives, or a payback provision if the agreed term of production and subsidy support is not completed. Duration, including any tapering factor, needs to be clearly communicated, as in the IRA and PLI.

5.4.2. Concessional Finance

Overview

Access to capital was highlighted as key barrier for potential solar PV manufacturers, with stakeholders highlighting that a form of concessional finance will be critical to the success of setting up an Australian domestic solar PV supply chain.

Concessional finance is granted by governments to address investment uncertainty for businesses and refers to financial support provided to companies at a below-market interest rate or with more favourable terms. Governments often offer concessional finance to fund early-stage or high-risk projects that have a potentially high social or environmental impact. Providing low-cost or patient finance allows projects with a higher risk profile access to capital, while allowing government to recoup upfront costs over time.

In Australia, concessional finance can be granted to clean energy and sustainable projects through the Clean Energy Finance Corporation (CEFC) and will be awarded to renewables and low emissions technologies through the newly announced National Reconstruction Fund (NRF) *(see case studies below)*.

Case Study: Australia - Clean Energy Finance Corporation (CEFC)

The CEFC is a statutory authority established by the Australian Government which aims to facilitate increased finance flows into Australia's clean energy sector. It does so by providing a variety of investment solutions, such as debt and equity finance. In the 2022/2023 year, the CEFC made 1.2bn AUD worth of investments in renewable energy and grid-related investment commitments. Its investments in large-scale projects and funds usually start from 20m AUD, with smaller-scale projects receiving between 10,000-5m AUD in finance (from the CEFC's asset finance programs). However, the CEFC aims to deliver a positive return for taxpayers, and as such, sparingly applies concessionality in its investments.

Case Study: Australia – Northern Australia Infrastructure Facility (NAIF)

The NAIF is also an Australian Government entity financing infrastructure projects and businesses, but it only does so in Northern Australia (parts of the Northern Territory, Queensland and Western Australia above the Tropic of Capricorn). It supports projects and businesses across a variety of sectors like energy but has certain investment criteria such as the project needing to involve the development or material enhancement of infrastructure, be of public benefit, be located in/have significant benefit for Northern Australia, provide a return for the fund, and have an Indigenous engagement strategy. It provides a range of financing products, such as loan and equity finance. While each project is independently considered, it generally focuses on loans of 15m AUD and above. It has the ability to provide concessional financing, but this cannot be below the combined Commonwealth cost of borrowing and administrative costs.

Case Study: Australia - National Reconstruction Fund (NRF)

The NRF is a 15bn AUD fund that provides finance for projects in the forms of loans, equity investment, and guarantees. It has certain priority areas such as renewables and low emissions technologies (with 3bn AUD allocated to this priority area) and will operate commercially to deliver a positive rate of return across all its investments. It aims to enable Australian industry to address supply chain vulnerabilities and leverage the competitive strengths of Australia. However, there is currently no indication of when the fund may be operational.

In general, concessional finance can take various forms, including concessional loans, equity investment or guarantees. These three mechanisms, which could feasibly be implemented in Australia, are described further below.

- **Concessional/discounted loan:** financial support provided to companies of a targeted industry at below-market interest rate or with more favourable terms (such as longer repayment terms or grace periods) compared to standard commercial loans.
- **Equity investment:** companies receive capital in exchange for a share of their profits and control over operations. Concessional equity investments provided by governments generally require lower returns, offer longer exit horizons and have a higher risk tolerance than equity investments by private players.
- **Guarantees:** The government takes responsibility for a portion of the debt or other obligations the manufacturer might have, should the manufacturer default through contractual assurance. Guarantees improve access to private capital for solar PV manufacturers, as it reduces the risks and cost of financing for establishing facilities.

Quantitative Analysis

The quantitative analysis evaluates the size of support needed to be competitive with China and assesses the impact a policy lever has on closing the cost gap (refer to section 5.1. for the policy assessment methodology).

When applied to the Australian solar PV manufacturing context, quantitative assessment indicates that concessional loans are not effective at bridging the cost gap for any of the supply chain segments over a 10-year production period *(see Figure* 5-5*, Figure* 5-6*, Figure* 5-7*, Figure* 5-8*)*. However, concessional finance does address investment uncertainty and access to capital for businesses. In combination with other targeted financial support, concessional finance may sufficiently address critical upfront barriers identified by industry.

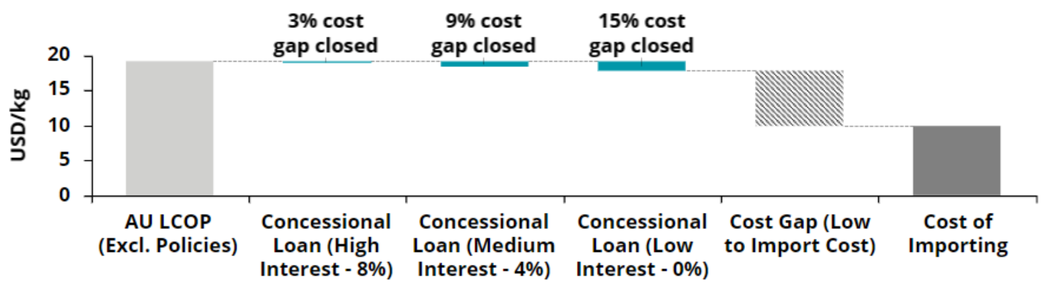


Figure 5-5: Impact of concessional loans for poly-Si

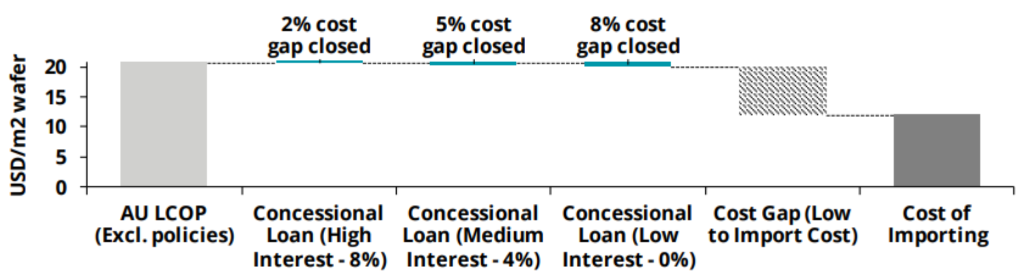


Figure 5-6: Impact of concessional loans for ingot/wafer

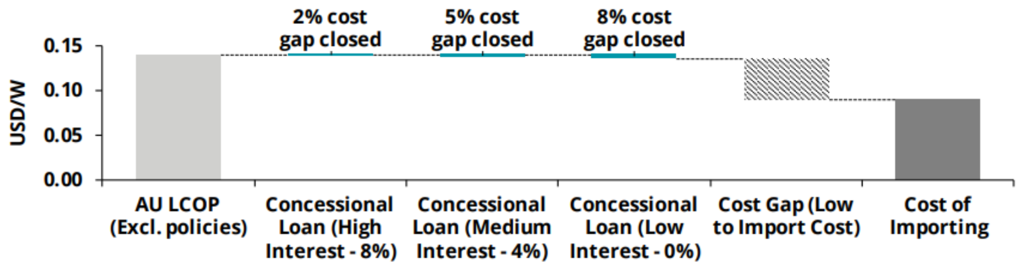


Figure 5-7: Impact of concessional loans for cells

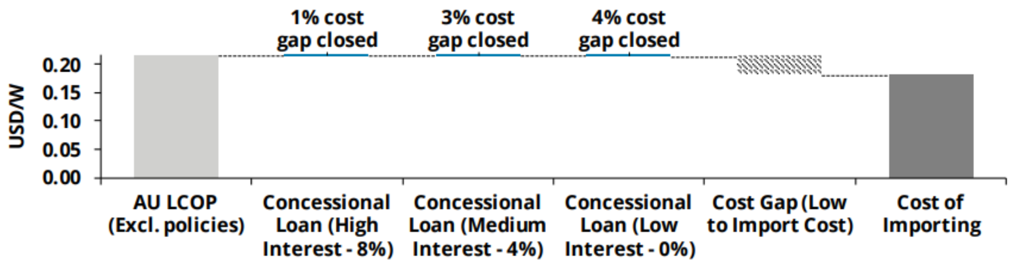


Figure 5-8: Impact of concessional loans for modules

The total cost to government to support a facility of minium viable scale over a five year concessional loan period is presented in Table 18 below. The total cost in this instance is considered a loss in revenue from provision of a 0% interest rate loan, rather than a cost.

Table 18: Total support required to provide concessional loans of different interest rates[156]

Step	Size supported	Total support required (discounted)			Average annual support over 5 years (undiscounted)
		High Interest (8%)	Medium Interest (4%)	Low Interest (0%)	Low interest (0%)
Poly-Si	10 GW	~44.1m USD (~62.6m AUD)	~127.1m USD (~180.5m AUD)	~203.2m USD (~288.5m AUD)	~49.1m USD (~69.7m AUD)
Ingot/wafer	1 GW	~4.1m USD (~5.8m AUD)	~11.7m USD (~16.7m AUD)	~18.8m USD (~26.6m AUD)	~4.5m USD (~6.4m AUD)
Cell	1 GW	~5.3m USD (~7.5m AUD)	~15.3m USD (~21.7m AUD)	~24.5m USD	~5.9m USD (~8.4m AUD)

[156] Exchange rate used for USD to AUD: 0.7045 USD/AUD (average of 2023/4 to 2026/7, Deloitte Access Economics, https://www.deloitte.com/au/en/about/press-room/business-outlook.html, viewed 24 Oct 2023). Minor discrepancies may exist due to rounding of the numbers.

				(~34.7m AUD)	
Module	1 GW	~1.9m USD (~2.7m AUD)	~5.5m USD (~7.8m AUD)	~8.8m USD (~12.5m AUD)	~2.1m USD (~3.0m AUD)

Conclusion

Even at a zero percent interest rate, concessional loans are not effective at bridging the cost gap for any of the supply chain segments. However, concessional finance does address investment uncertainty for businesses and provides access to capital which may otherwise be hard to raise. Highly concessional loans for solar PV manufacturing can be feasibly implemented in Australia through existing agencies and funds, such as the CEFC and NRF. In combination with other targeted financial support, concessional finance may sufficiently address critical upfront barriers identified by industry.

5.4.3. CAPEX Support

Overview

Interested investors have highlighted the higher capital expenditure in Australia for setting up manufacturing capacity as an important barrier, specifically for construction (material, labour and land), import of international equipment (e.g., from the modification of equipment to meet higher safety and environmental standards and shipping costs) and import of expertise for commissioning. The capital-intensive upstream supply chain segments in particular have stressed the need for upfront capital support.

CAPEX support is granted by governments to alleviate the high upfront capital costs associated with setting up manufacturing capability. This type of non-repayable support can take the form of capital grants, infrastructure subsidies, or concessional land and equipment.

Capital grants are a common policy mechanism in Australia and have historically been widely implemented by other governments. For renewable technologies, the most common funding agency is the Australian Renewable Energy Agency (ARENA). Grants are one of the main ways that ARENA funds eligible applicants, with the amount usually granted as a percentage of the total project cost.

In other jurisdictions such as the US and Canada *(see case studies below)*, capital support is granted through an investment tax credit. Stakeholder interviews have identified that the investment tax credit under the IRA is key for companies facing high capital expenditure. The optionality between the investment tax credit and the production tax credit *(see case study under 5.4.15.4.1 Production-linked support)* allows CAPEX-heavy supply chain segments, such as poly-Si, to opt for the investment credit instead of the production credit. The former credit offers a large upfront amount of capital, whereas the latter offers support over time, based on production and sales. In Australia, the option of upfront versus ongoing support could be offered to allow industry players to choose the support that is the most effective for them.

As for the IRA, the support could be granted through a competitive process where projects are ranked against environmental and societal considerations and a certain amount of support is reserved for projects located in areas affected by the energy transition. The latter could especially be relevant for Australia to consider, being a fossil-fuel exporting country.

	Case Study: US –Investment Tax Credit in IRA (48c)[157, 158]
Overarching policy/strategy	The US Inflation Reduction Act (IRA) has the objective of curbing greenhouse gas emissions and reducing the cost of energy by investing in domestic green energy production
Support size	The IRA offers 10bn USD in investment tax credits for domestic manufacturing of components for solar and wind energy, inverters, battery components, and critical minerals. Projects are selected through a competitive process, with 4bn USD available in the first round. 1.6bn USD of this amount is reserved for projects in energy communities.
Eligibility	To be eligible for the credit, production should take place in the United States or United States possession. The allocation of support will aim for portfolio diversity (different sizes of projects, different technologies supported and geographically dispersed across the US). In general, the criteria projects are assessed against are the following: • The commercial viability of the project (e.g., shortest project timeline, lowest levelised cost of energy, consideration of risk mitigation strategies,etc.) but also projects that have the greatest potential for technological innovation • Net impact on greenhouse gas reduction (including direct, indirect, and lifecycle emissions) • Ability to strengthen US supply chains (for the first round, this included for solar PV the following priority production areas: poly-Si, wafer, ingot/wafer production equipment and solar glass) • Workforce and community engagement (greatest direct and indirect domestic job creation, reduction of barriers that might increase project completion time,etc.).
Mechanism	Under the IRA, manufacturers must choose between the production tax credit (45x) or the investment tax credit (48c), as the support is not stackable. The credit is an upfront tax credit based on the capital investment in a manufacturing facility and can be offset against federal corporate income tax imposed on the taxpayer. The base credit amount is 6% of taxpayer's qualifying investment.

[157] Office of Energy Efficiency & Renewable Energy, https://www.energy.gov/eere/solar/federal-tax-credits-solar-manufacturers, viewed 24 Oct 2023.
[158] Office of Energy Efficiency & Renewable Energy, https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses, viewed 24 Oct 2023.

	Businesses can claim a 30% credit for projects when meeting prevailing wage and registered apprenticeship requirements. The credit is available when the application and certification process begins and ends when credits are fully allocated.
Considerations	Credits are transferable: all or a portion of credits can be sold to another eligible taxpayer to receive a cash payment. A direct payment is possible for manufacturers if they are a tax-exempt organization.

Similar to the US, Canada also offers an Investment Tax Credit to solar PV manufacturers as a form of CAPEX support. The credit is phased down starting from 2032 and ends in 2034, being notably two years longer in effect than the US IRA support.

	Case Study: Canada – Clean Technology Manufacturing Tax Credit[159,160]
Overarching policy/strategy	In response to the US Inflation Reduction Act, Canada announced 80bn CAD in support for clean energy and sustainable infrastructure as part of its 2023 budget.
Support size	The announced support includes "Clean Investment Tax Credits" for clean technology manufacturing and processing, and critical mineral extraction and processing. The tax credits represent over 60bn CAD in funding over 10 years.
Duration	The Clean Technology Manufacturing Tax Credit will be phased down between 2032 and 2034, after 2034 the credit will no longer be in place (30% in 2024 to 2031, 20% in 2032, 10% in 2033, and 5% in 2034).
Considerations	Manufacturers can stack the credit with the existing Atlantic investment tax credit.

Quantitative Analysis

The quantitative analysis evaluates the size of support needed to be competitive with China and assesses the impact a policy lever has on closing the cost gap (refer to section 5.1. for the policy assessment methodology).

[159] Government of Canada, https://www.canada.ca/en/revenue-agency/services/tax/businesses/topics/corporations/whats-new-corporations.html, viewed 24 Oct 2023.
[160] Government of Canada, https://www.canada.ca/en/environment-climate-change/news/2023/04/minister-guilbeault-highlights-the-big-five-new-clean-investment-tax-credits-in-budget-2023-to-support-sustainable-made-in-canada-clean-economy.html, viewed 24 Oct 2023.

When applied to the Australian solar PV manufacturing context, quantitative assessment indicates that the modelled scenarios of capital grants[161] are not effective at bridging the cost gap for any of the supply chain segments *(see Figure* 5-9, *Figure* 5-10, *Figure* 5-11, *Figure* 5-12*)*. When modelled to represent the improbable scenario of 100% of capital expenditure, the capital grant achieves the highest impact for poly-Si and ingot/wafer, the most capital-intensive segments of the solar PV supply chain.

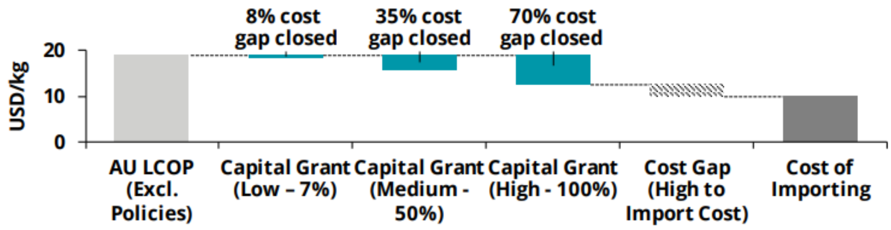


Figure 5-9: Impact of capital grants for poly-Si

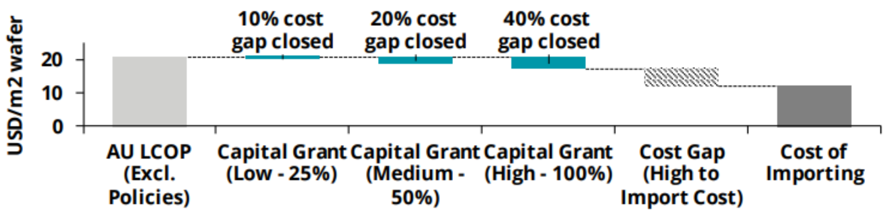


Figure 5-10: Impact of capital grants for ingot/wafer

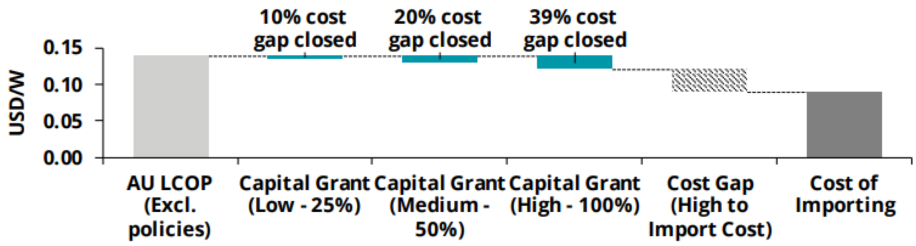


Figure 5-11: Impact of capital grants for cells

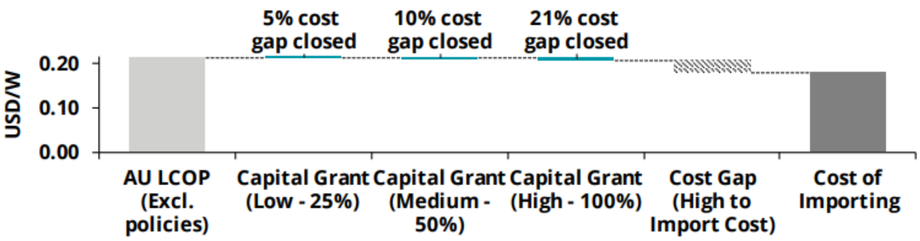


Figure 5-12: Impact of capital grants for modules

The total cost to government to support a facility with grants of different sizes is presented in Table 19 below.

[161] Note: for analysis purpose, the sizing of grants was selected as a percentage of total upfront capital costs. For poly-Si, due to the high upfront capital spend, a 'Low' scenario of 100m USD (7%) was selected to represent a scenario more consistent with historical grant spend in Australia.

Table 19: Total support required to implement different grant levels[162]

Step	Size supported (per annum)	Total support required (discounted)		
		Low Grant	Medium Grant	High Grant
Poly-Si	10 GW	100m USD (~142.0m AUD)	~453.9m USD (~644.3m AUD)	~907.8m USD (~1.3bn AUD)
Ingot/wafer	1 GW	~20.9m USD (~29.7m AUD)	~49.1m USD (~59.5m AUD)	~83.8m USD (~118.9m AUD)
Cell	1 GW	~27.3m USD (~38.8m AUD)	~54.6m USD (~77.6m AUD)	~109.3m USD (~155.2m AUD)
Module	1 GW	~9.8m USD (~13.4m AUD)	19.7m USD (~28.0m AUD)	39.4m USD (~56m AUD)

Conclusion

Whilst in isolation not effective at bridging the cost gap, stakeholders especially in upstream supply chain segments, have indicated that a form of CAPEX support is important in the final policy mix. This could take the form of a capital grant, concessional land or leases, or infrastructure subsidies.

The risk associated with grants depends on the size of support granted. Of the different supply-side policy levers, government wears the most risk of project failure with grants, as grants are a form of non-repayable support that is rewarded upfront. Especially when given to a single player this creates a significant exposure and multiple grants should ideally be issued to different players to ensure competition (note that this would not be possible for poly-Si, where only one plant is likely to be developed). While risks can be mitigated through the sizing of the grant or by awarding grants through competitive processes and making payments when specific milestones are achieved, governments have been scrutinised for grants not achieving the expected outcome and giving the wrong incentives.

5.4.4. Electricity Price Guarantees

Overview

[162] Exchange rate used for USD to AUD: 0.7045 USD/AUD (average of 2023/4 to 2026/7, Deloitte Access Economics, https://www.deloitte.com/au/en/about/press-room/business-outlook.html, viewed 24 Oct 2023). Minor discrepancies may exist due to rounding of the numbers.

Australia currently has relatively high electricity prices compared to several global peers, especially for firmed renewable electricity, particularly those with abundant and cheap hydroelectric power such as China, Canada and the Nordic countries. In addition, price increases and volatility in the wholesale electricity market over the past year have led to additional price uncertainty. High electricity prices and future price uncertainty are a concern for the energy-intensive supply chain steps, in particular poly-Si production. Stakeholders in poly-Si have highlighted that a form of electricity support could be critical for production in Australia.

Electricity price guarantees are adopted by governments to reduce the electricity costs of energy-intensive domestic industries and provide price certainty for large energy users via a stable, lower or subsidised electricity price to manufacturers. Mechanisms that could feasibly be implemented in Australia are described further below. As energy markets come under state or territory jurisdiction, these policy levers would likely be implemented by State governments. However, they could be coordinated at the federal level to ensure national consistency.

1) **Contract for Difference (1-way):** A contract for difference (CfD) between electricity generators and the government, is an agreement that ensures the electricity generator receives a fixed price for its produced electricity, regardless of market price fluctuations. In a one-way CfD, the government pays the generator the difference between the fixed agreed price and the wholesale market price, when the market price is lower than the fixed price. Governments can implement the reverse mechanism to guarantee a maximum electricity price for solar PV manufacturers. If the market price of electricity increases above the cap price during the contract period, government compensates the manufacturer for the price difference.
2) **Contract for Difference (2-way):** In a two-way contract for difference between electricity generators and the government, electricity generators have to pay or receive the difference between the market price and the agreed price to government when the former is higher than the latter, thus sharing the risk. Governments can implement the reverse mechanism to guarantee a maximum electricity price for solar PV manufacturers but share the risk of electricity price fluctuations. If the market price of electricity increases above the cap price during the contract period, government compensates the manufacturer for the price difference. However, when the market price falls below the cap price, manufacturers would pay the difference back to government.
3) **Direct government subsidy through long-term electricity price contracts (government as intermediary)**: Government can act as an intermediary by running firm renewable energy auctions, thereby ensuring through the bids a minimum amount of renewable electricity at a maximum price. The government can subsequently sell this electricity for a guaranteed concessional price to manufacturers in the solar PV supply chain. Through this mechanism, government reduces the risk of being exposed to market price fluctuations and therefore uncertain total costs to government.
4) **Government as credit provider of last resort:** When government cannot provide guaranteed electricity prices because of costs or implementation complexities, it can operate as a credit provider of last resort. If the solar PV manufacturer goes bankrupt, government would pay outstanding debts to the electricity provider. Although this may not achieve a sufficient reduction in the long-term electricity price for a manufacturer, it would give industry a stronger case when privately negotiating bulk energy contracts or PPAs for guaranteed

competitive prices with energy suppliers. Being a new industry and therefore having a higher risk profile, privately securing lower electricity prices could be difficult for Australian PV manufacturers.

Providing electricity subsidies to strategic businesses is not an uncommon practice to Australian State and Federal governments. The Australian Aluminium industry, identified as a strategic sector, has a long history of substantial electricity price subsidies from both State and Federal government to keep smelters operational, with details highly confidential, and often criticised for the high cost to government and taxpayers. A poly-Si facility has an electricity consumption of a comparable order of magnitude as the Portland aluminium smelter, however a demand response mechanism, as applied to the smelter, would not be feasible, as the poly-Si facility would need a high stable baseload to operate *(see case study)*.

Case Study: Australia – Aluminium Electricity Subsidies

In Australia, the energy-intensive aluminium industry (considered to be a strategic sector) has a long history of receiving government support to remain operational in Australia and overcome high electricity prices.

Federal and State governments have historically provided energy relief or facilitated the negotiation of long-term electricity supply contracts to secure competitive and stable electricity prices, with details of the arrangements not publicly available. Estimates from the Australia Institute in 1999 indicated that aluminium smelters were believed to be paying between 1.5 – 2.5c/kWh for delivered electricity compared to around 5 – 6 c/kWh by other large industrial users (i.e., subsidies resulting in Aluminium smelters paying approximately 1/3 of the market price).

For example, the Alcoa aluminium smelter in Portland, Victoria (which accounts for nearly 10% of Victoria's electricity demand), secured **150m AUD in federal and state government support from 2021 through 2025** to secure a multi-party long-term electricity supply contract. Although the financial terms of the energy agreements are confidential, it is known that part of the funding will underwrite the smelters participation in the Reliability and Emergency Reserve Trader (RERT) scheme, to cut its energy use during periods of peak demand. The recent subsidy agreement for the Tomago smelter in NSW, which constitutes 15% of state electricity demand, is also known to incorporate a demand response mechanism to provide relief during periods of peak load.

Criticisms of the recent Portland smelter subsidies included that there were **no pre-conditions to transition to renewable energy.**

In New South Wales, electricity support is given to producers of green hydrogen, through reduced network charges *(see case study)*. To receive network charge concessions for green hydrogen in NSW, eligibility requirements include that the electrolyser must be placed in parts of the network with spare capacity. Due to the large electricity requirements of a poly-Si plant, this requirement would not be feasible in Australia and the policy design would have to be adapted.

Case Study: NSW – Green hydrogen: reduced network charges[163, 164]	
Overarching policy/strategy	The New South Wales government is providing temporary network concessions to green hydrogen producers in an effort to encourage production. The concessions form part of 3bn AUD in incentives under the NSW Green Hydrogen Strategy.
Support size	Green hydrogen producers that align with eligibility criteria can apply for 30-100% exemptions from schemes levied on electricity consumers, and 90% exemptions from network service charges.
Start/Duration	The concessions will be available by 2024, and for a period of 12 years. From this point onwards the hydrogen producers will have to pay the full charges.
Mechanism	The concessions are applicable for existing spare capacity for which revenue is already set and being paid for by customers, therefore, this policy will not result in a cost to government (taxpayers) or NSPs, but rather a redistribution of costs to other electricity users. Network businesses and the electricity market operator will be able to direct the electrolyser to turn off if required during a peak event.
Considerations	NSW will review timeframes and conditions in 2027 to guarantee the concessions are still appropriate. The hydrogen producers will not be exempt from paying the full charges (they pay approximately 10%), as that would place the full cost burden on other consumers.
Impact	In NSW, network costs make up between 30-40% of the electricity bill. For Australia in general, DCCEEW reports that network service charges can represent about 10-20% of total costs for large energy users.[165]

The high cost to taxpayers made the German government reject a recent proposal that would guarantee electricity prices for its strategic energy-intensive businesses through a contract for difference mechanism *(see case study)*.

[163] Department of Planning, Industry and Environment, "NSW Hydrogen Strategy", October 2021.
[164] IPART, https://www.ipart.nsw.gov.au/1-july-2023-electricity-price-increases, viewed 24 Oct 2023.
[165] DCCEEW, https://www.energy.gov.au/business/energy-management-business/large-energy-users/energy-procurement/understand-your-retail-energy-bill, viewed 24 Oct 2023.

Case Study: Germany – Electricity price cap (Contract for Difference mechanism)

The EU's energy prices spiked after the start of the war in Ukraine. Germany, one of the European countries most reliant on Russian gas, was especially hit, resulting in requests for support from industries. Concerns that lower energy costs in the US and the financial support included in the Inflation Reduction Act would cause companies to relocate to the US, prompted politicians to take action. A Contract for Difference mechanism was proposed by the German Minister of Economy in May 2023. The policy proposal was targeted towards supporting **strategic energy-intensive industries**, like chemicals, steel and glass manufacturing and prevent them from leaving Germany.

The proposal included a capped electricity price of 0.06 EUR/kWh (approx. 0.07 USD). Companies would be compensated for the difference between the market price for electricity and the suggested cap **until 2030**. **Estimates of the total cost of the support amounted to 25-30bn EUR.**

The proposal was **welcomed by industry** but received **criticism** from the opposition, as it would imply using very large sums of public funds to subsidise some of Germany's most polluting industries and would only benefit a small amount of big industrial players. Moreover, the EU commission could regard it as unfair subsidization of the German industry.

The German Government finally rejected the proposal at the end of August 2023.

The province of Ontario in Canada offered reduced electricity prices to industry through the Industrial Electricity Incentive Program. However, the support was province-based, and possible in Ontario because it has abundant surplus electricity from state-owned hydro and nuclear power plants. These plants cannot be easily turned off or ramped down when producing excess electricity. Support was only given to specific energy-intensive and strategic industries and required a minimum investment.

Case Study: Ontario – Industrial Electricity Incentive Program

Launched in 2013, the program had the objective **of creating new jobs in the industrial sector** and attracting industry investment. Ontario used its surplus energy supply to guarantee lower electricity prices to companies in energy-intensive sectors, such as the manufacturing and resource extraction sectors.

Contract terms varied on the size of the project, but firms were eligible to **receive contracts up to 20 years at 5.5 cents CAD/kWh.**

In the third stream of the program in 2014, contracts were offered for either 10 years or an end date of Dec 31, 2024, whichever is shorter.

Proposals were ranked by the **economic and job benefits** they bring; companies that meet requirements have access to long-term reduced electricity prices.

In 2013, conditions for companies establishing new operations included making a **minimum investment of 250m CAD**.

Quantitative Analysis

The quantitative analysis evaluates the size of support needed to be competitive with China and assesses the impact a policy lever has on closing the cost gap (refer to Section 5.1. for the policy assessment methodology).

When applied to the Australian solar PV manufacturing context, quantitative assessment indicates that the modelled scenarios of electricity price guarantees are not effective at bridging the cost gap for any of the supply chain segments *(see Figure* 5-13*, Figure* 5-14*, Figure* 5-15*, Figure* 5-16*)*. However, guaranteed electricity prices do provide predictability to industry players in terms of electricity costs. The certainty provided can in turn help these segments with investment decisions and securing private capital. The figures and table below illustrate the impact of different electricity price guarantees on closing the cost cap, and the total support required to implement them.

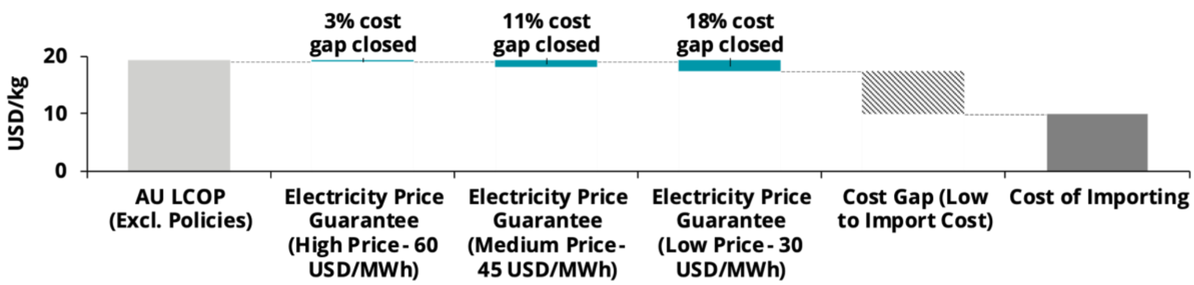


Figure 5-13: Impact of electricity price guarantees for poly-Si

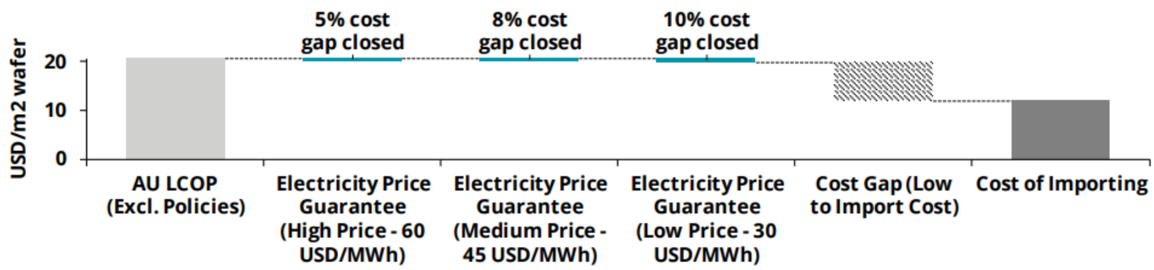


Figure 5-14: Impact of electricity price guarantees for ingot/wafer

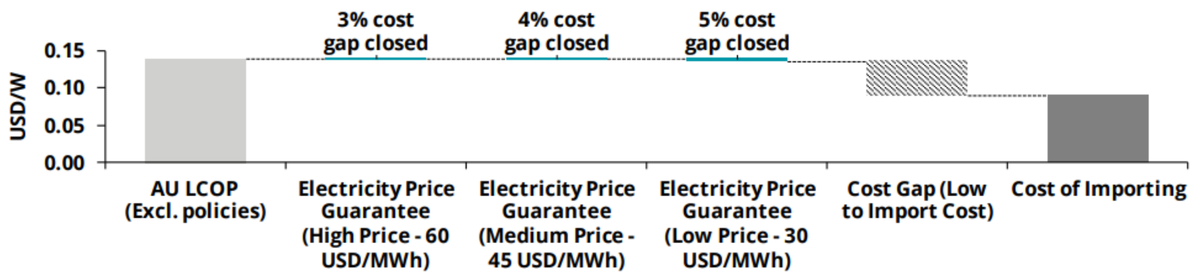


Figure 5-15: Impact of electricity price guarantees for cells

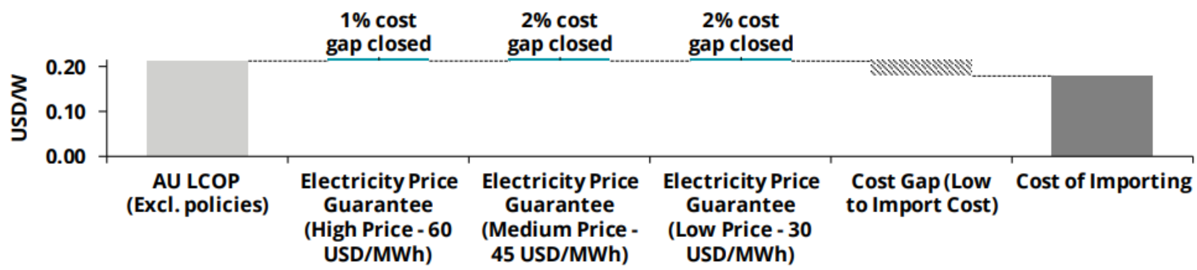


Figure 5-16: Impact of electricity price guarantees for modules

The total cost to government to support a facility of minimum viable scale with different levels of electricity price guarantees over a 10-year production period, is presented in Table 20 below.

Table 20: Total support required to implement different electricity price guarantees[166]

Step	Size supported (per annum)	Total support required (discounted)			Annual support over 10 years (undiscounted)
		High Price (60 USD/MWh)	Medium Price (45 USD/MWh)	Low Price (30 USD/MWh)	Low Price (30 USD/MWh)
Poly-Si	10 GW	~40.2m USD (~57.1m AUD)	~160.8m USD (~228.3m AUD)	~281.4m USD (~399.5m AUD)	~42.9m USD (~60.9m AUD)
Ingot/wafer	1 GW	~12.8m USD (~18.2m AUD)	~19.3m USD (~27.3m AUD)	25.7m USD (~36.5m AUD)	3.9m USD (~5.6m AUD)
Cell	1 GW	8.9m USD	13.4m USD	17.8m USD	2.7m USD

[166] Exchange rate used for USD to AUD: 0.7045 USD/AUD (average of 2023/4 to 2026/7, Deloitte Access Economics, https://www.deloitte.com/au/en/about/press-room/business-outlook.html, viewed 24 Oct 2023). Minor discrepancies may exist due to rounding of the numbers.

		(~12.6m AUD)	(~19.0m AUD)	(~25.3m AUD)	(~3.9m AUD)
Module	1 GW	2.5m USD (~3.5m AUD)	3.7m USD (~5.2m AUD)	4.9m USD (~7.0m AUD)	0.75m USD (~1.1m AUD)

Conclusion

Realistic scenarios of electricity price guarantees modelled show they are not effective at bridging the cost gap for any of the supply chain segments. Nevertheless, guaranteed electricity prices do provide predictability to industry players in terms of electricity costs, which is especially relevant for the electricity-intensive supply chain segments like poly-Si, and to a lesser extent wafers. The certainty provided can in turn help these segments with investment decisions and securing private capital.

Defending the electricity subsidisation of one industry may be difficult, especially if it is for one facility only, as in the case of poly-Si. Direct measures like enforcing an electricity price cap on retailers, are highly unlikely for governments to adopt, as it may discourage investment in new power generation and infrastructure. Contracts for difference imply a high administrative burden and have a high total cost for government uncertainty due to volatility of electricity prices, increasing the risk of a large price tag for taxpayers.

However, state-owned energy companies might be able to offer fixed price contracts to strategic industry players. Contracts for difference can be implemented as 2-way contracts, with a cap on total government support and price revision opportunities.

On the other hand, government can also indirectly play a role in reducing electricity prices, by signalling the strategic importance of the solar PV industry and that it is willing to support the industry financially in the long term. It could also go a step further and operate as reseller of lower-cost electricity or as a credit provider of last resort. Although this may not achieve a sufficient price reduction in the long-term electricity price, it would give industry a stronger case when privately negotiating bulk energy contracts or PPAs for guaranteed competitive prices from energy suppliers.

Additionally, large sums of electricity support should be coupled with low-carbon and energy-efficiency eligibility requirements to align with Australia's long-term net-zero goals and to mitigate risks of energy-intensive and/or polluting industries not adopting more energy-efficient or green practices. This is often met with severe opposition, as seen in the case of the aluminium smelter subsidies in Australia and the proposed electricity price cap in Germany.

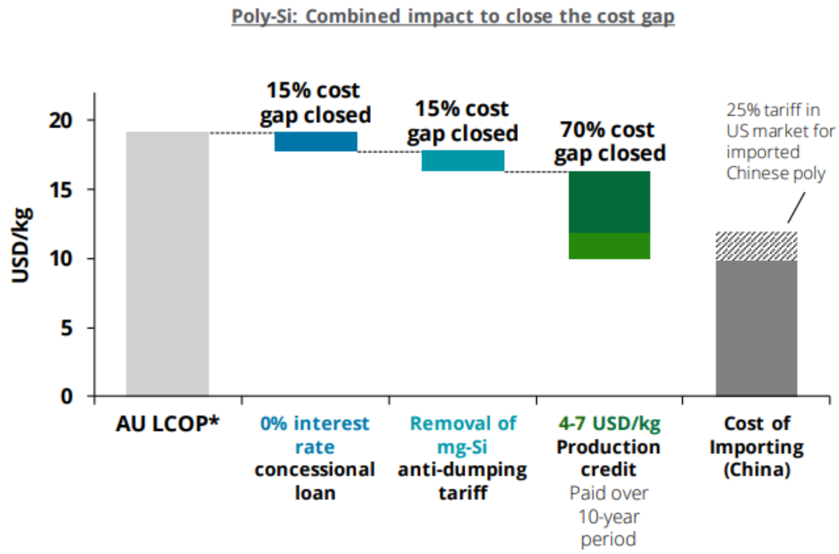
Providing renewable electricity for large energy users like a poly-Si facility should also be met with additional renewable capacity, therefore putting the necessary conditions in place to accelerate capacity building (such as strengthening the grid, accelerating planning and approvals, grid connections).

5.4.5. Combined Impact: Production Credit and Concessional Finance

Quantitative Analysis

The quantitative assessment shows that a combination of concessional finance with a production credit address both the barriers of access to upfront capital and the need for ongoing financial support, and are the most effective policy levers to close the cost gap for Australian solar PV manufacturers.

The combination of an interest free concessional loan with an appropriately sized production credit would be effective at bridging the cost gap to China over a 10-year production period *(see Figure* 5-17*, Figure* 5-18*, Figure* 5-19*, Figure* 5-20*).* This presents a sensitivity of maximum support required to be competitive with China and not impact the cost of the energy transition, however, less support may be needed depending on project-specific considerations.



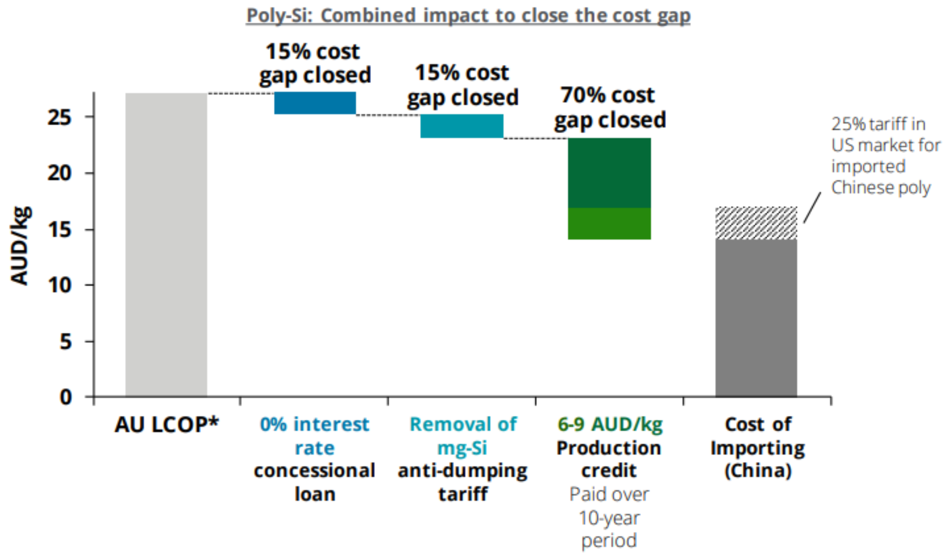


Figure 5-17: Combined policy impact for poly-Si (in USD and AUD)

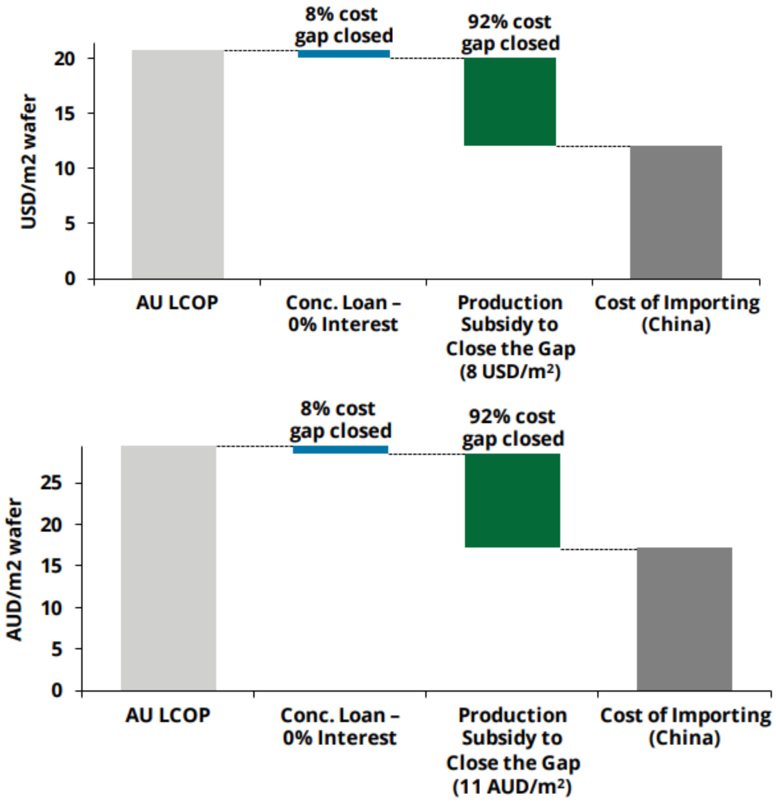


Figure 5-18: Combined policy impact for ingot/wafer (in USD and AUD)

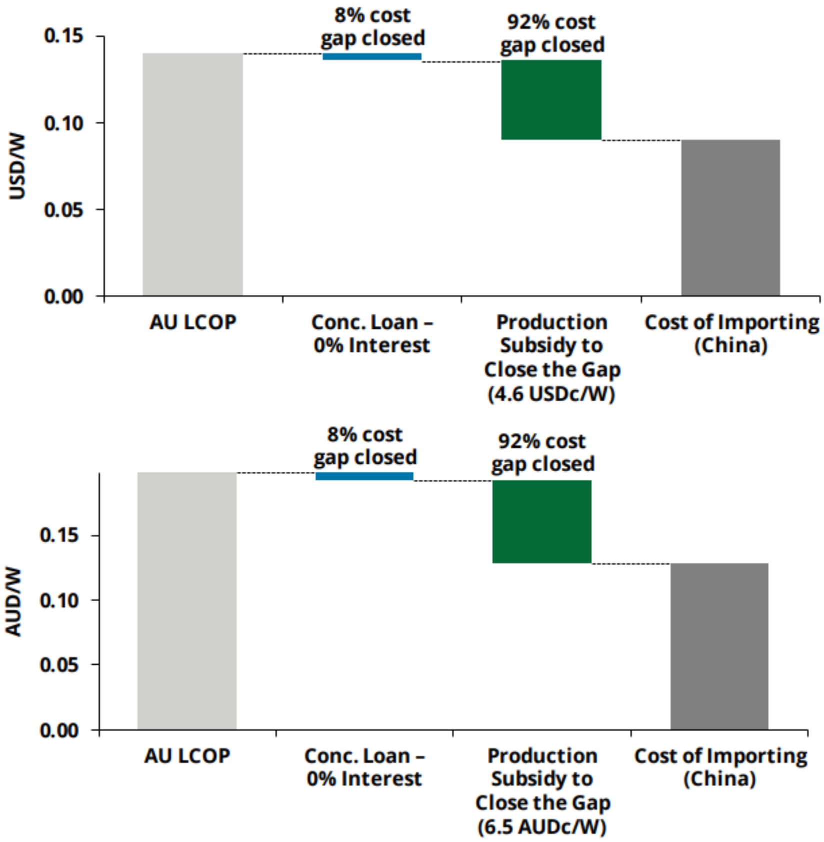


Figure 5-19: Combined policy impact for cells (in USD and AUD)

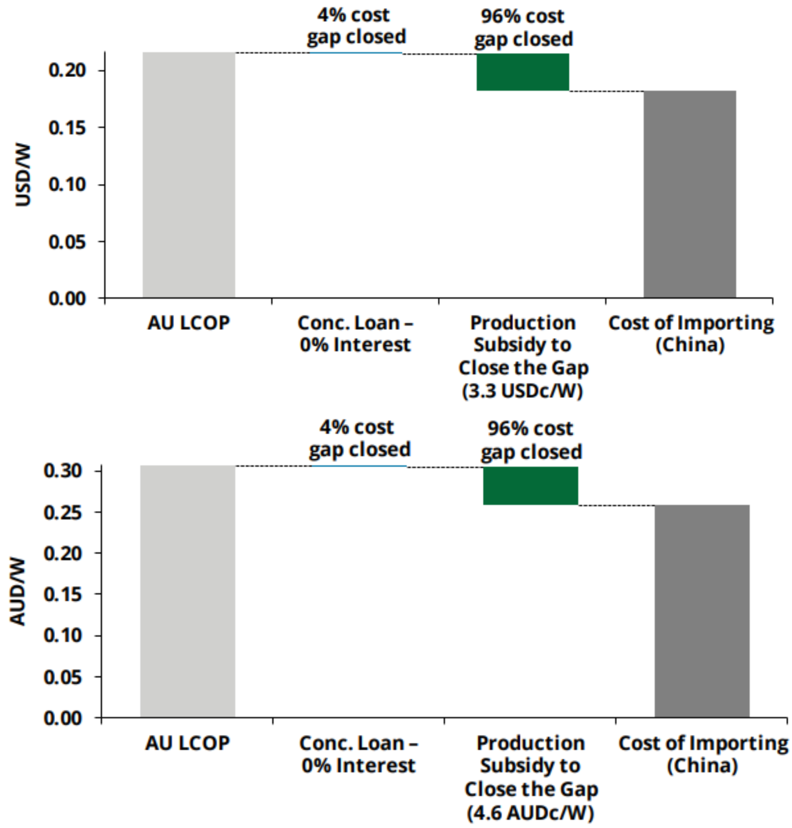


Figure 5-20: Combined policy impact for modules (in USD and AUD)

The total cost to government to support a facility of mininum viable scale over a ten year production period is presented in Table 21 below. The total cost of the concessional loan component is considered a loss in revenue from provision of a 0% interest rate loan.

Table 21: Total support required to close the cost gap – combination of production credit and concessional loan.

Production Step	Production credit	Concessional loan	Total support required over 10-year period for combined impact (discounted)[167]	
			Minimum viable scale 10 GW of poly-Si 1GW of Ingot/wafer, cell and modules	*Target scale* 10 GW of poly-Si 5GW of Ingot/wafer, cell and modules
Poly-Si	~9.2 AUD/kg (~6.5 USD/kg)	0% interest	~2.1bn AUD	~2.1bn AUD
Ingot & wafer	~11.3 AUD/m^2 (~8.0 USD/m^2)	0% interest	~350m AUD	~1.8bn AUD

[167] Exchange rate used for USD to AUD: 0.7045 USD/AUD (average of 2023/4 to 2026/7, Deloitte Access Economics, https://www.deloitte.com/au/en/about/press-room/business-outlook.html, viewed 24 Oct 2023). Minor discrepancies may exist due to rounding of the numbers.

Cell	~6.5 AUDc/W (~4.6 USDc/W)	0% interest	~459m AUD	~2.3bn AUD
Module	~4.6 AUDc/W (~3.3 USDc/W)	0% interest	~317m AUD	~1.6bn AUD
Total estimated support for the full value chain over a 10-year period (discounted)			Total estimated support for the full value chain over a 10-year period (discounted)	~3.2bn AUD (~5.1bn USD)

Note: For poly-Si, this analysis includes the impact of removal of the mg-Si anti-dumping tariff that is currently imposed on Chinese importers to Australia. Additionally, if exporting to the US or EU, less support may be required to make a theoretical facility competitive for the US market due to the presence of a 25% import tariff on Chinese products in the US and historical market price stratification in the semi-conductor industry.

Conclusion

A production credit combined with a form of concessional finance are effective policy levers to close the cost gap for Australian manufacturers.

Production-linked support could be allocated based on a reverse auction tender process, with applicants applying based on nominated volumes to be produced and the subsidy size required. Support should be provided as a direct subsidy payment rather than a tax credit such as in the US IRA, to maximise ability of facilities to access support, even if they are loss-making, and minimise administrative complexities associated with trading of credits on a second-hand market. To minimise risks to government key design features should include:

- A support cap to provide government cost certainty.
- Upside sharing or funding reduction features linked to increased market sales prices.
- A payback provision if the agreed term of production and subsidy support is not completed.
- Clear communication of duration and gradual phase-out, to mitigate risks of overreliance on support.
- Sizing of support in alignment with priority sectors for development, and in consideration of competitiveness with other jurisdictions.

Eligibility requirements and assessment criteria linked to benefit sharing and key social and environmental objectives (refer to

- Table 22 for international case study examples), to ensure alignment with other government policy objectives (e.g., delivering emissions reductions, ensuring shared benefits and a just energy transition for local communities, encouraging continuous innovation, and creating a diversified local circular economy, etc.) and mitigate risks of a tunnel vision on volumes.

Highly concessional finance can be facilitated by government through low-interest loans, equity investments or guarantees. Clear eligibility of the solar PV manufacturing sector is essential, as well as a clear differentiation from commercial debt and equity in terms of risk appetite, return requirements and other investment terms.

Alternative supply side support may be considered by government, e.g., through the provision of capital grants or electricity price guarantees. This may be particularly appropriate for a poly-Si facility, given the capital and energy intensity of the facilities, the large minimum scale of production, and the potential to access price-premium offtake markets (and hence require less support). However, this support in isolation would not be sufficient to close the cost gap to imported products from China.

Governments **should consider the design considerations** mentioned in

Table 22 when setting up the support (A summary of policy design recommendations is further outlined in Section 7.2.87.2):

Table 22: Possible eligibility criteria for support

Consideration	International Case Study	Application to Australia
Labour standards and wages	The renewable electricity production tax credit for PV developers in the IRA can be raised from 0.55 US cents/kWh to 2.75 US cents/kWh when specific labour requirements are met. More specifically, Davis-Bacon Act prevailing wages must be paid to workers and registered apprentices utilized. [168]	This is not a critical issue for Australia, though it will be important to monitor employment conditions, especially if international workers are brought in during the establishment phase.
Renewable energy use	The successful recipients of solar PV manufacturing support in India's PLI, are required to source at least 20% of the manufacturing plant's electricity consumption from renewable energy sources. [169]	For Australia, a higher percentage would ensure access to EU and other markets.
Locating in low-income areas or indigenous land	The investment tax credit for PV developers in the IRA can be raised with 10% when the project is located in a low-income community or on indigenous land.[170]	For Australia, negotiations may be required for development of large-scale solar farms, or potentially production facilities, on Aboriginal land. The APVI has already been contacted by Aboriginal Corporations interested in developing opportunities for their communities.

[168] US Department of Energy, https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses, viewed 24 Oct 2023.
[169] Ministry of New and Renewable Energy, https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/08/2023080863.pdf, viewed 24 Oct 2023.
[170] US Department of Energy, https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses, viewed 24 Oct 2023.

Locating in areas transitioning away from a fossil-fuel based economy	The renewable electricity production tax credit for PV developers in the IRA can be raised by 10% when a project is located in an "energy community". [171]	Areas transitioning away from fossil fuels are also of interest in Australia, with several State government programs targeting new industrial development to replace fossil fuel jobs.
Circularity and recycling	The successful recipients of solar PV support in India's PLI are required to set up facilities for recovery and recycling of solar waste and encouraged to adopt circular economy principles in their production processes and supply chains. [172]	Recycling is a key focus for the federal and several State governments. It will be important to integrate it into local PV manufacturing support.
Technology performance	To encourage R&D and innovation, module manufacturers receive more/less support under India's PLI depending on the efficiency of the produced modules.[173]	Similar approaches could be a key link to Australia's world-leading PV research teams.

[171] US Department of Energy, https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses, viewed 24 Oct 2023.
[172] Ministry of New and Renewable Energy, https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/08/2023080863.pdf, viewed 24 Oct 2023.
[173] Ministry of New and Renewable Energy, https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/08/2023080863.pdf, viewed 24 Oct 2023.

6. Where Should Australia Participate?

6.1. Balancing Different Strategies and Pathways

When considering the need for a diversified solar PV value chain and where Australia should focus its efforts, the government needs to consider priorities across a range of factors at each step of the value chain, including vulnerability/ criticality, Australia's competitive advantage, industry interest to establish capability, and broader benefits to the economy *(highlighted in Figure* 6-1*)*.

The decision on which sectors to support and the value in supporting a fully integrated domestic value chain with export potential at ingot/wafer and poly-Si steps will depend on government priorities and objectives. This includes balancing the benefits of establishing a fully integrated domestic value chain compared to participating in a globally diversified value chain through international partnerships and contracting arrangements. The following sections explore the different factors in Figure 6-1 below in greater detail.

Relatively Lower → Relatively Higher

Value chain step (minimum viable scale)	**Poly-Si** (10GW)	**Ingot/Wafer** (1GW)	**Cell** (1GW)	**Module** (1GW)
Vulnerability/criticality [1]	Moderate	Higher	Moderate	Lower
Competitive advantage [2]	Moderate	Moderate	Lower	Lower
Existing industry interest [3]	Higher	Moderate	Moderate	Higher
Initial capital investment	~1.3bn AUD	~119m AUD	~155m AUD	~56m AUD
Direct jobs [4]	520 FTE	190 FTE	240 FTE	260 FTE
LCOP Cost gap % (absolute) [5]	93% greater (3.3 AUDc/W)	72% greater (5.4 AUDc/W)	55% greater (7.0 AUDc/W)	19% greater (4.8 AUDc/W)
Offtake market focus	Domestic + export	Domestic + export	Domestic	Domestic

Figure 6-1: Considerations for PV manufacturing development pathways

Notes: 1. % concentration in the supply chain 2. Competitive advantage rankings based on key metrics as presented in Appendix C 3. Existing industry interest rankings based on stakeholder engagement 4. Assuming that Australia will require 20% higher headcount than China 5. Based on quantitative analysis of the Levelised cost of production (LCOP) and estimated cost to import from China. Further information on analysis is provided in Appendix B.

5.4.5. Supply Chain Vulnerability

Government's ability to manage supply chain risks and become resilient to shocks depends on the vulnerability and criticality of each supply chain segment, and consideration of where Australia can rely on other countries and complement international diversification efforts.

The criticality/vulnerability varies across each step of the solar value chain. Developing domestic capability across all steps of the supply chain would provide maximum insurance to supply chain disruptions and concentration risks and ensure Australia can meet domestic demand through domestic manufacturing capability. However, Australia may also be able to play a role at key vulnerable/critical steps as part of a globally diversified supply chain solution. This would result in ongoing reliance on other countries for certain steps.

Developing capability only at the module end, which is the least concentrated and vulnerable, would not necessarily overcome limitations in supply of inputs in earlier steps of the value chain. Ingot/wafering in particular has reached a critical level of concentration, due to highly specialised state-of-the-art technology and equipment only available in China. While poly-Si is slightly more diversified, including through manufacturing capacity from Wacker Chemie in Germany, a large portion of this is targeted for the higher (price-premium) semi-conductor industry. Existing project announcements coming out the of the US IRA have indicated a large shortfall in poly-Si and ingot/wafer capacity. In contrast, increasing cell manufacturing capacity is becoming evident in both South-east Asia and the US. Therefore, Australia can consider playing a role in the most concentrated and vulnerable steps of the supply chain, namely ingots/wafers and poly-Si, to complement global capability developments.

5.4.6. Competitive Advantage

Developing successful and sustainable manufacturing capability should focus on areas where Australia has or can develop competitive advantage compared to other jurisdictions.

Table 23: Australia's competitive advantage compared to other jurisdictions manufacturing PV products.

Relative disadvantage → Relative advantage

Factors underpinning competitive advantage		Proxy Metric*	AU	CN	SEA	US	EU	IN	ME
Capex	Construction costs	*Construction cost index*							
Electricity	Renewable energy potential	*Solar potential (specific PV power output)*							
	Cost of grid electricity (current)	*USD/kWh*							
Demand	Domestic offtake potential	*Forecast annual solar capacity increase*							
Labour	Cost of labour	*Average manufacturing salary (USD/month)*						N/A	N/A
	Labour standards	*Existing labour practices/ standards*							
Materials	High-quality quartz/ mg-Si supply	*Presence of local industry (Y/Ann./N)*							
	Domestic solar glass/ Al industries	*Presence of local industry (Y/Ann./N)*							
IP	Solar PV R&D capability	*# dedicated research institutions*							
	Access to Chinese IP/ technology	*Trade relationship with China*		N/A					
General	International investment certainty	*Ease of doing business index*							
	Export infrastructure	*Logistics performance index*							
	Manufacturing expertise	*Economic complexity index*							
	Existing policy support	*Case studies/stakeholder engagement*			N/A				

Note: The table above shows a high-level assessment of Australia's competitive advantage compared to other jurisdictions. The chosen metric may not fully reflect the factor but is used as a proxy. Ratings for each metric are scored on a relative and not absolute basis. A country is scored with "N/A" (not assessed) when the source does not include information for the country or region. Refer to appendix for underlying analysis AU – Australia; CN – China, SEA – South-east Asia; US – United States, EU – Europe; IN – India; ME – Middle East.

An assessment of Australia's competitive advantage for overarching factors underpinning solar PV manufacturing is presented in Table 23 above. This assessment is based on proxy metrics to score performance of regions on a relative basis and may not fully reflect the factor it is representing. In addition, international stakeholder insights on 'attractiveness' of certain factors in Australia was taken into consideration. Details on each proxy metric used are presented in Appendix F.

Overall, Stakeholders indicated that Australia is an attractive location for establishing a solar PV manufacturing industry compared to other regions, due to its strong trade relationships and existing status as a credible energy exporter, political stability, high labour standards, solar PV R&D capability, and existing bulk commodity export infrastructure (including roads, rail, and ports). While current average emissions intensity of the grid is comparable to or higher than other regions, Australia's high renewable energy potential (particularly for solar power) make it an attractive location for manufacturing of energy intensive goods, through co-location with behind the meter assets or location in regions that have lower emissions intensities, such as South Australia or Tasmania. Large scale development of firmed renewable energy will drive down grid emissions and electricity costs over time. Consequently, Australia should have one of the most competitive positions globally in the long run when it comes to low-cost, renewable energy.

However, Australia's relatively higher costs of labour and construction, lack of manufacturing expertise, absence of supporting policies and financial support put Australia at a disadvantage compared to other regions. Australia can mitigate these disadvantages over time through provision of clear and direct policy support for clean energy manufacturing.

Potential areas of competitive advantage for individual steps of the value chain are further outlined in Sections 4.1.3, 4.2.2, 4.3.3, and 4.4.3. In summary:

- Poly-Si: as a highly electricity intensive process, Australia's abundant renewable energy potential makes Australia particularly attractive for poly-Si manufacturing. This competitive advantage should cement over time, with increased penetration of renewables in the grid and reductions in emissions intensity and electricity costs, if Australia achieves its ambition of becoming a renewable energy superpower. While not geographically unique, Australia's high quality quartz deposits, existing mg-Si smelting capacity and existing bulk commodity export infrastructure further add to Australia's advantage. In addition, Australia's high labour standards and health and safety controls are an appealing factor for investors, given hazards associated with use and storage of highly flammable/combustible chemicals such as trichlorosilane (TCS) and recent forced labour allegations in the Xinjiang region in China.
- Ingot/wafering: While the primary cost drivers underlying manufacturing of ingots/wafers do not naturally favour Australia (cost of labour and high upfront capex), Australia is also not highly disadvantaged in these categories compared to other OECD states such as the US and EU. Given the concentration of technology/IP for ingot/wafering in China, Australia's history of close collaboration with China in the PV industry could cement advantages and opportunities compared to these other regions when requiring Chinese expertise to establish local ingot/wafer manufacturing capability.
- Cells: Australia does not have a clear competitive cost advantage in cell manufacturing. However, Australia has a long history of expertise in cell technology development and was at

the forefront of different cell innovations. If cell manufacturing in Australia is re-established, further improvements in technology could capitalise on this ongoing innovation and expertise in the country.

- **Modules:** Australia's competitive advantage in module manufacturing is considered to be limited when considering underlying cost drivers and opportunities for technology diversification. However, existing large domestic PV demand potential and local glass and aluminium production may present future opportunities to support integrated low-carbon domestic manufacturing and reduce both emissions and costs from module production and shipping.

5.4.7. Existing Industry Interest

Tapping successfully into an upcoming market and achieving the best return on taxpayer investment will be guided by existing industry interest.

Australia is competing on a global stage to attract investment in the solar PV industry and the required manufacturing capability. Industry has indicated that factors mentioned in the competitive advantage table above make Australia an attractive investment location, however, high costs and lack of strong government signals and policy support are eroding this advantage.

Different Australian industry players have expressed interest in building up capacity if the right government signals were given and policy were to be set in place. Some international companies have confirmed interest in possible joint ventures with Australian companies as well.

While there is industry interest in all sections of the value chain, interest is highest in the poly-Si and module steps. Further details on industry interest and potential players are provided in Section 2.2.2.

5.4.8. Economic Benefits

The choice of which value chain segment to support should consider the economic and societal benefits created and where these flow.

Initial capital investment required for each step of the value chain is highest at the poly-Si step and decreases along the value chain with lowest investment required at the module stage. This is clearly scaled by the minimum viable facility size of 10 GW for poly-Si. Ongoing operational costs and payment of company tax on revenue would have further economic implications.

In addition, estimates of direct jobs created via the techno-economic assessment indicate that cells and modules, as the most labour-intensive steps of the value chain, would create the most direct manufacturing jobs per GW of capacity. However, due to the reliance of the poly-Si and ingot/wafer steps on international manufacturing and technology expertise, and associated complexity of skill requirements, these jobs may provide additional productivity and knowledge overflow benefits to other sectors in Australia. Therefore, both the complexity and number of jobs created need to be considered to assess economic benefits of each sector. An in-depth economic benefits assessment could provide more insights on number and complexity of direct and indirect jobs created, as well as value-add to the Australian economy and skill/knowledge transfer opportunities for adjacent industries.

Given that both the poly-Si and ingot/wafer steps of the value chain would likely be developed for an export focus, the potential revenue from sales to price-premium markets such as the US and EU presents additional economic opportunities at these steps. As outlined in Section 5.4.5, this is due to the presence of a 25% import tariff on Chinese poly-Si in the US and historical market price stratification due to bill of material transparency import standards and associated supply shortfalls.

5.4.9. Production Cost Gap

Government can decide to prioritize steps that are least competitive right now and need support the most (highest LCOP cost gap) or support steps that are currently the most competitive (lowest LCOP cost gap).[174]

Assessing which step of the value chain to prioritise, and the magnitude of support required, will require balancing of factors outlined above and the financial support required by each step. Given the discrepancy in minimum viable scale of a poly-Si facility compared to other steps, absolute support required for poly-Si is substantially higher. However, when considering the support required on a per GW annual output basis, support required is highest for cells (0.045 USD/W), followed by ingots/wafers (0.035 USD/W), poly-Si (0.023 USD/W) and modules (0.031 USD/W). This does not change the fact that the percentage of the gap of the LCOP comparing the manufacturing costs in China and Australia is the largest at the poly-Si stage and smallest at the solar module stage.

6.2. Development Pathways

Different domestic industry building pathways can be developed, depending on the balancing of government priorities and factors outlined above. Three potential future pathways are outlined in Figure 6-2 below. Regardless of development pathway, poly-Si can only feasibly come online in the medium term, due to anticipated development timelines of 3-5 years minimum.

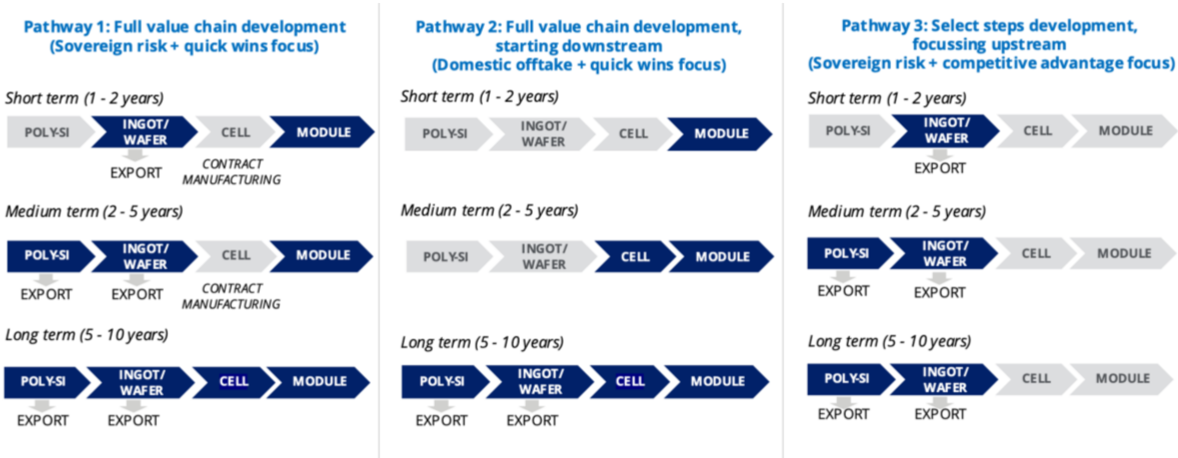


Figure 6-2: Industry development pathways

Pathway 1 focuses on addressing supply chain concentration at the ingot/wafer step, while tapping into the "quick win" of establishing domestic module capability. Poly-Si and ingot/wafer would have

[174] Note: These cost gap estimates assume that the previous value chain step is sourced from China, or from an Australian industry that has been supported to be price competitive with the import price from China.

an export focus in the absence of cell manufacturing capacity, while module assembly could cater to a domestic offtake market as soon as it is developed. Poly-Si and ingot/wafer could then be scaled to continue this export focus in the long-term, following establishment of the full value chain, to complement global supply chain diversification efforts.

Pathway 2 adopts a domestic offtake focus and starts downstream with module and cell manufacturing capability, as demand for these segments exists domestically and developing them presents the least cost to government. This pathway implies building module capacity in the short term, shifting towards cell manufacturing in the medium term, and shifting further upstream to poly-Si and wafers in the long term.

Pathway 3 does not develop the whole value chain and instead focuses on select steps of the value chain with higher supply chain concentration and/or competitive advantage. This strategy would take an export lens and position Australia as a credible partner in global solar PV supply chains. In this scenario, Australia would need to have established import relationships to diversify supply for its modules, for example with India or Southeast Asia.

6.3. International Partnerships

In general, developing export and contract manufacturing relationships with third countries presents an opportunity to fill value chain gaps and develop a fully diversified supply chain where Australia does not develop domestic capability, or in the short term. The partnerships will depend on the development pathway Australian government support focuses on *(see Section 6.2)*. Figure 6-3 below presents options for different partner countries, depending on which capabilities Australia develops.

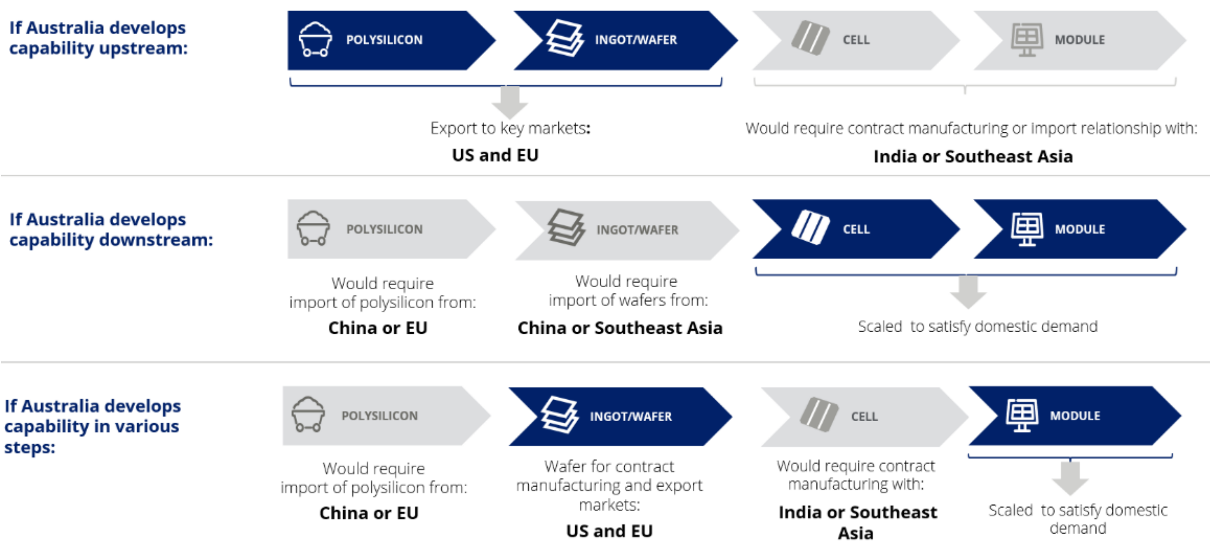


Figure 6-3: International partnerships for import/export and contract manufacturing of solar PV products

7. Conclusion: Paving the Way Forward for Australia

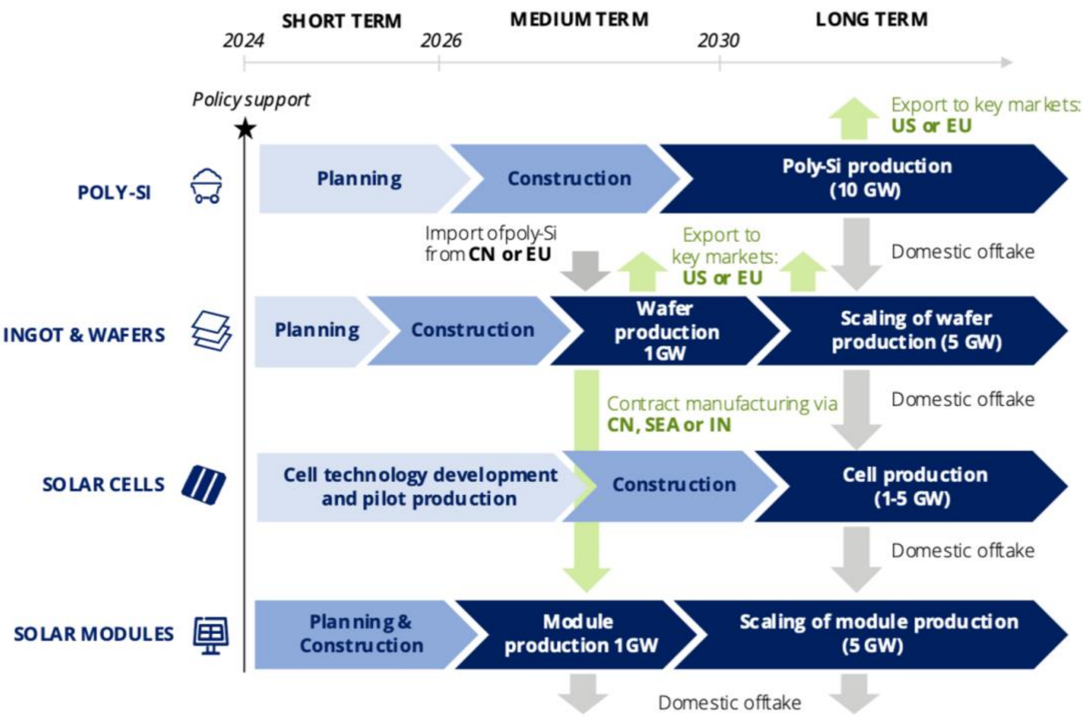
The energy transition and shifts in geopolitical settings are bringing in a new era of green industrial policy. Major economies such as the US, EU and India have only recently introduced unprecedented policy support to expand their domestic PV manufacturing capability – this changes the playing field and requires reconsideration of where Australia can and should play a role.

Australia cannot necessarily match or compete with the magnitude of funding support provided by other major economies with significantly larger spending power. However, these economies are developing domestic manufacturing capability for reasons other than market efficiency – reasons such as energy security, supply chain security, and the opportunity to become a first mover and capture value in future low carbon technologies that will be necessary in a globally decarbonised economy. It is highly unlikely that any new solar PV manufacturing capacity in the US, EU and India will be sufficient to meet their own domestic demand, let alone have enough to supply to Australia. Therefore, Australia needs to consider the importance of securing PV supply to meet domestic demand and growth ambitions of becoming a renewable energy superpower.

7.1. Recommended Pathway

Figure 7-1 illustrates the recommended pathway for the build out of a fully integrated domestic supply chain over time. Figure 7-2 integrates the policy steps required to achieve this. The timelines presented assume provision of policy support from 2024.

- **At the poly-Si step**, Australia can be part of a globally diversified supply chain exporting particularly to the rapidly growing US and EU markets. Australia would export renewable energy-intensive value-added products and take control over poly-Si supply for the needs of the domestic solar market.
- **Ingot & wafer manufacturing addresses the most concentrated step in the solar value chain.** Australian wafers can be exported to the US, EU and other regions. Contract manufacturing overseas would enable domestically produced wafers to be used in local solar panels in the medium term.
- Rapid development of **cell technology** and large capacity scale up present a challenge to setting up viable cell production domestically. Australia's strong track record in cell research could lead to cutting-edge technology, however, R&D, prototyping and pilot lines require additional time.
- **Module production** represents a "low-hanging fruit" component of the value chain due to the smallest government support needed. However, building globally relevant and competitive module production is very challenging and Australian modules would likely be for the domestic market only.



CN – China, SEA – South-east Asia, IN – India, EU – Europe, US – United States

Figure 7-1: Roadmap for the recommended development pathway in Australia

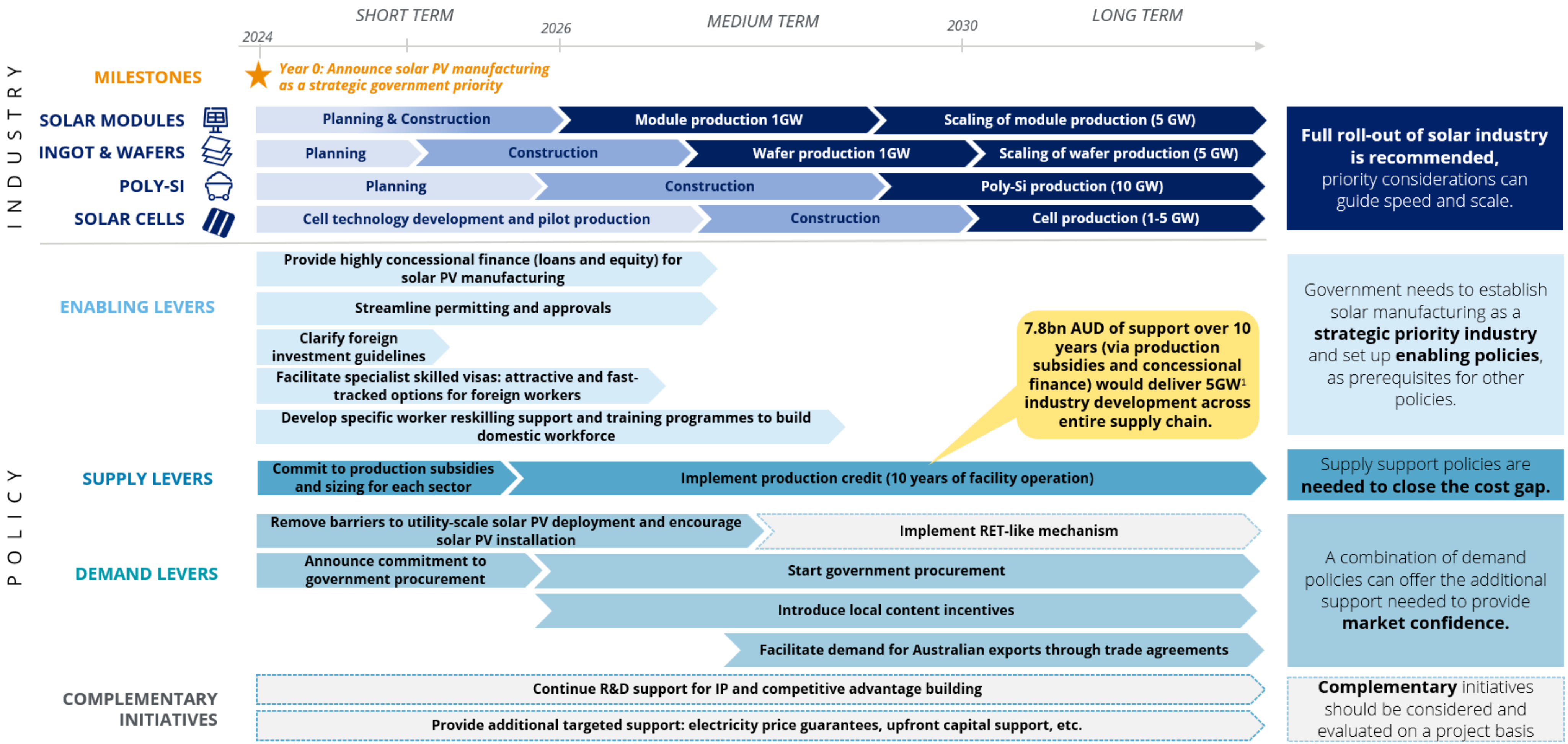


Figure 7-2 : Roadmap of industry and policy actions for PV manufacturing development in Australia

7.2. Summary of Policy Recommendations

Developing an economically viable, relevant, and timely solar PV manufacturing supply chain in Australia will require a comprehensive policy strategy. First and foremost, there are critical enabling requirements which need to be addressed to create an attractive investment environment and provide investment certainty during the project development phase. Additionally, demand levers to overcome offtake uncertainty and financial support to bridge the cost gap with imported products will be required to make an Australian industry competitive with international products. Any financial support provided must ensure appropriate policy design and selection/eligibility criteria to align with broader government objectives and ensure benefit sharing with the Australian public.

7.2.5. Enabling Factors to Unlock an Australian PV Manufacturing Industry

Regardless of the value chain step, key barriers at the project development stage need to be addressed by government for successful industry establishment in Australia. Without this, direct or indirect financial support will unlikely be effective at attracting private investment to Australia.

Recommendation 1

Priorities

- Announcement/recognition of solar PV manufacturing as a strategic government priority
- Explicit inclusion of solar PV manufacturing as an eligible sector for existing and recommended support mechanisms further outlined below.
- Consider definition of a national target for solar PV manufacturing (e.g., 20% of annual demand by 2030)

Recommendation 2
Permits

- Provide clear upfront guidance and streamlined processes for permitting and approvals
- Provision of a targeted pre-approval engagement service for solar PV manufacturing facilities to enhance clarity and certainty on application requirements, timelines and outcomes.
- Commitment to accelerated processing timeframes through increased staffing of government agencies, or maximum application processing timeframes.
- Increased coordination between government agencies to ensure timely delivery and outcomes of approvals.
- Publication of sector-specific guidance for emerging priority sectors such as solar PV manufacturing
- Streamlining of community engagement and feedback periods.
- Government facilitation of place-based environmental planning for strategic industrial hubs.

Recommendation 3
Partners

- Provide clear and early direction on joint ventures or partnerships with foreign investors
- Clear guidance on acceptable foreign investment and joint venture / partnership requirements for the solar PV manufacturing sector.
- Early engagement between industry and government on acceptable foreign investment parameters.

Note: additional support recommended in this study should be prioritised for Australian companies through competitive selection processes and eligibility criteria.

Recommendation 4

People

- Short term: Ensure streamlined visa pathways exist for international solar PV manufacturing workers in the short-term, e.g., through the government's renewed Migration Strategy.
- Add trades with specialist solar PV manufacturing skill shortages to the priority migration skilled occupation list.
- Commitment to a set number and processing timeline of streamlined skilled worker permits or visas to support solar PV manufacturing facilities. These could be linked to domestic workforce training requirements for international partner companies.
- Short – medium term: Develop specific local worker reskilling support and training programmes
- Promote collaboration between industry and academic institutions to set-up the relevant PV manufacturing training courses and apprenticeships.
- Provide subsidised training programmes for workers entering solar PV manufacturing.
- Provide additional industrial workforce incentives e.g., by linking industrial clusters with affordable housing, affordable quality childcare and schools, public transport and other amenities.

Recommendation 5

Concessional Finance

- Facilitate highly concessional finance (equity, loan or guarantees) for solar PV manufacturing to secure upfront capital investment. This could be implemented via existing mechanisms, such as the NRF.
- Clear statement of eligibility for the solar PV manufacturing sector, including eligibility of existing commercialised technologies.
- Provide clear differentiation to commercial debt and equity in terms of risk appetite, return requirements and other investment terms.
- If implemented through the NRF, this requires a clear definition of the investment mandate.

7.2.6. Demand-side Support

Domestic demand-side support for industry will be key to provide offtake and revenue certainty for investment decisions. The type of support required will likely evolve over time, in line with the scale and maturity of industry development in Australia. The identified barriers to industry development can be addressed with the following levers:

Recommendation 6

Demand-side Certainty

Short to medium term: Announce commitment to government procurement and implement processes on both federal and state level that favour local module procurement

- Commitment from federal and State governments to procure a minimum % of annual PV module demand from local producers (where available)
- Commitment to further stimulate the roll out of PV on public buildings.
- Local procurement can be extended to support the broader Australian green manufacturing industry, such as locally produced batteries, electric vehicles, etc.

Medium to long term: Implement a form of local content incentive/bonus:

- Local content incentives or requirements in renewable energy industrial precinct (REIP) and renewable energy priority regions selection process
- Local content bonus for solar PV developers: e.g., through the RET or an alternative system. The scope could be broadened to include locally produced batteries, wind components and other green energy products, thereby supporting the efforts made in other clean energy supply chains.

Recommendation 7

Facilitate Demand for Australian Exports

Facilitate preferential trade arrangements and international partnerships with key economies for solar PV components, such as through the Australia – US Compact and Joint India – Australia Solar taskforce.

Remove barriers for low-carbon production of poly-Si and ingots/wafers to ensure success of Australian exports in target EU and US markets and minimise the impact of future carbon tariffs. This requires government support to accelerate additional large-scale renewable energy deployment will be critical to ensure sufficient access to additional renewable energy supply for energy-intensive poly-Si and ingot/wafer facilities.

Recommendation 8

Facilitate Domestic Deployment

Short term: Remove barriers to utility-scale solar PV deployment:

- Link grid transmission infrastructure to new production centres.
- Facilitate and coordinate planning of network investments and grid connection process.
- Streamline approvals, without undermining social and environmental concerns.
- Address installation skill shortages (engineers, technicians, electricians, etc.).

Short term: Encourage solar PV installation by continuing the RET beyond 2030 or adopting a similar incentive would provide incentives to utility-scale PV developers as well as individuals and businesses to install solar PV.

7.2.7. Supply-side Support

Implement a production credit in combination with concessional finance (refer to Recommendation 5) to close the gap to imported products.

If sized to close the cost gap between the cost of production and assumed competitive sales price for a fixed number of years, a production credit can provide substantial upfront investment certainty to industry and financial institutions. The ‘payment on results’ basis means that cost to government is only incurred if the production eventuates. In combination with concessional finance, this can effectively overcome both upfront capital and ongoing operational cost barriers. Note that production credits could be sized to close the cost gap with China, however, less support may be needed depending on project-specific considerations.

Recommendation 9

Production Credit

Production credits are an effective financial support lever to overcome the cost gap to international products, and can be applied as a uniform lever across all steps of the value chain, irrespective of underlying cost drivers (e.g., electricity, labour, materials). This would simplify administration across multiple sectors, and could be sized in accordance with government priorities and industry needs. Support could be designed to leverage the existing Hydrogen Headstart model, to minimise administrative complexities and send a clear signal to industry.

Design considerations

Support should be provided as a direct subsidy payment rather than a tax credit such as in the US IRA, to maximise ability of facilities to access support, even if they are loss-making, and minimise administrative complexities associated with trading of credits on a second-hand market. To minimise risks to government key design features should include:

- Allocation and sizing of support based on a reverse auction tender process, with applicants nominating volumes to be produced and subsidy size required.
- A support cap to provide government cost certainty.
- Upside sharing or funding reduction features linked to increased market sales prices.
- Eligibility requirements linked to key social and environmental objectives (refer to Section 7.2.8)
- A payback provision if the agreed term of production and subsidy support is not completed.
- Clear communication of duration and gradual phase-out, to mitigate risks of overreliance on support.
- Allocation of support in alignment with priority sectors for development, and in consideration of competitiveness with other jurisdictions.

Alternative combinations of other targeted financial support levers may be considered by governments to alleviate critical upfront barriers identified by industry:

Recommendation 10

Alternative and Additional Supply-side Support

- **Electricity price guarantee** – to provide certainty on electricity costs for energy-intensive production steps, to overcome barriers associated with current high electricity prices and uncertainty over price volatility. Support should be linked to clear firmed renewable energy requirements over time.
- **Upfront capital support** – to incentivise construction. In the form of an upfront capital grant or in the form of concessional land and infrastructure (e.g., long-term concessional land lease in industrial precincts, with existing road, rail, electricity and utility connections).
- **Continued R&D support** – to foster Australian IP development and innovation and build up sustained competitive advantage.

The provision of capital grants or electricity price guarantees may be particularly appropriate for a poly-Si facility, given the capital and energy intensity of the facilities, the large minimum scale of production, and the potential to access price-premium offtake markets (and hence require less support). However, this support in isolation would not be sufficient to close the cost gap to imported products from China.

7.2.8. Key Eligibility Considerations for Support

Regardless of the policy lever selected, support should be clearly linked to well defined assessment and/or eligibility criteria, to guarantee the use of public funds ensures benefit sharing with the Australian public, as well as meeting broader sustainability and social license objectives. The green energy transition will lead to unprecedented social shifts and broad support among the Australian population is essential in achieving Australia's net-zero goals. Support eligibility criteria can include the following considerations:

Recommendation 11

Decarbonised Electricity Supply and Additionality

- Link support with decarbonised electricity supply – 'additionality'
- Subsidisation of energy-intensive industries should be clearly linked to decarbonised electricity requirements and encourage adoption of more energy-efficient practices.
- Renewable electricity for a facility should be additional and dedicated to the extent possible, to not detract from existing electrification and decarbonisation efforts.

Recommendation 12

Worker Reskilling and Training

- Financial support for new facilities should be linked to worker reskilling and training requirements where possible, such as through partnerships with universities and TAFE, commitment to knowledge sharing, etc.
- In the case where companies are structured as international partnerships/JVs, this may include requirements on foreign skilled worker visas linked to domestic training requirements.

Recommendation 13

PV Recycling and Circularity Requirements

Financial support given to solar PV manufacturers can be coupled with eligibility requirements to develop capabilities for PV recycling. This could be implemented through development of a **product stewardship scheme** to mandate recycling at the federal level and put the onus on manufacturers or importers to ensure all panels produced will be collected and recycled at the end of the product life.

Recommendation 14

Locating in Areas Transitioning Away from a Fossil-fuel-based Economy

Financial support should include eligibility criteria or incentives to encourage locating in areas affected by the energy transition, such as existing industrial hubs or regions with retiring coal mines and power plants.

Recommendation 15

Repayment Clause and Consumer Price Protection

To protect the use taxpayer money, provision of support may be linked to a repayment clause should a minimum operational period or production period not be met. In addition, financial support can be linked to a domestic supply requirement, to ensure prioritised sale of end-products to Australian consumers at reasonable prices. This can prevent domestic supply shortfalls should international market dynamics become more favourable for an Australian export market.

7.3. Closing Remarks

The Silicon to Solar Study has developed a roadmap for the successful development of a solar PV manufacturing industry in Australia and recommended a list of actions as outlined in this report. The roadmap delivers on three distinctive objectives:

(i) mitigate the risks of a single source of solar module supply (*Risk mitigation*),
(ii) provide and attract the investment to build a solar industry for domestic demand and export opportunities (*Return*), and
(iii) start to bring back sophisticated manufacturing capabilities to reverse the trend of a decline of Australia's economic complexity (*Reward*).

If acted upon in full, the roadmap will deliver a domestic solar industry of 10 GW of poly-Si and 5 GW each of ingot/wafer, cells and solar modules. The Roadmap, including optional intermediate steps is illustrated in Figure 7-3.

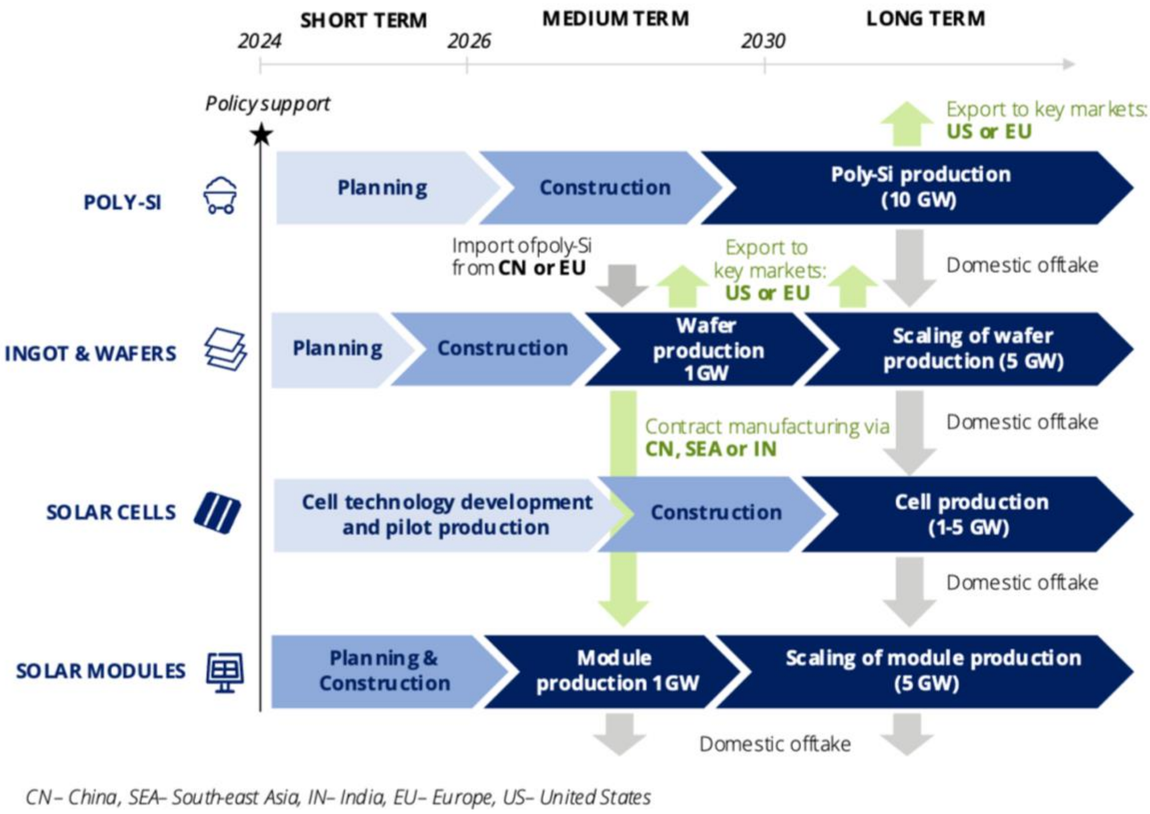


Figure 7-3: S2S roadmap to develop an Australian solar industry

The priority considerations of the Australian government will determine if all or only some steps of the solar value chain will be developed. Delivering on the three distinctive objectives; *Risk Mitigation, Return and Reward,* would have direct and broader impact on Australia's economy as listed in Figure 7-4 below:

Figure 7-4: Risk mitigation benefits, immediate returns and long-term rewards of domestic solar PV manufacturing

Immediate actions by government will be needed to ensure viable, relevant and timely industry development. The policy actions can be summarised as follows:

Immediately:

- Declare the solar PV manufacturing a strategic priority industry.
- Determine government alignment with the solar value chain development roadmap outlined in this report.
- Set up a Solar Manufacturing Taskforce to implement and deliver next steps and recommendations.

Next 12 months:

- Prioritise roll out of enabling support for people, permits and partners.
- Develop implementation structure to allocate and deliver financial supply-side support (concessional finance and production credits).
- Design frameworks for demand-side support (government procurement, circular economy and local content incentives).
- Continue to remove barriers for accelerated solar PV deployment.
- Strive for broad political support.
- Secure budget for the selected framework of subsidies.

Years 1 – 5:

- Implement concessional finance and production credit support for 10 years of facility operation.
- Start government procurement.
- Introduce local content incentives.
- Continue R&D support.
- Consider the provision of targeted support of electricity price guarantees.
- Consider the provision of additional up-front capital support.
- Implement a RET-like mechanism of mandated solar PV installations.

The development of the full solar supply chain of 10 GW/year of poly-Si and 5 GW/year of ingot & wafer, cell and module manufacturing in Australia will require the financial commitment discussed in this report. Ultimately, the decision to act upon the recommended steps comes down to political will, setting the right priorities and showing leadership in the transition phase to a globally decarbonised world economy, because Australia has the capability, capacity and now a solar manufacturing roadmap.

Appendix A: Techno-Economic Modelling Assumptions

Data was collected from reputable source publications and discussions with manufacturers in China and Europe as well as companies considering the establishment of Australian production. From this data, a bottom-up cost model has been built for two scenarios:

- China (CN) - China-based production.
- Australia (AU) - Australia based production, assuming input materials are imported from China.

Because of the uncertainties of each input of the cost model, an uncertainty range was used for each parameter, from which a range of production costs was calculated using a Monte Carlo uncertainty approach.

Some of the input data is confidential and unable to be released, but the other assumptions are detailed in the following sections. In each table, the range of each input is indicated in the format <Mid> (<Low> - <High>).

Production Equipment Capital and Maintenance Costs

	Capacity Unit (Cap Unit)	Tool Capex CN (USD/Cap Unit)	Tool Capex AU (USD/Cap Unit)	Depreciation Time (Years)
Poly-Si	Tonne/year	9.1k (7.0k – 12k)	27k (21k - 35k)	10
Ingot + Wafer	MW/year	20k (16k - 27k)	41k (32k - 53k)	7
Cell	MW/year	25k (19k – 33k)	50k (39k – 65k)	5
Module	MW/year	7.7k (5.9k – 10k)	15k (12k – 20k)	5

Maintenance costs were assumed 3% of capital cost per year.

Building and Facility Capital and Maintenance Costs

	Capacity Unit (Cap Unit)	Building/Facility Capex CN (USD/Cap Unit)	Building/Facility Capex AU (USD/Cap Unit)	Depreciation Time (Years)
Poly-Si	Tonne/year	3.0k (2.3k – 3.9k)	9.1k (7.0k – 12k)	20
Ingot + Wafer	MW/year	18k (13k – 25k)	43k (31k – 60k)	20
Cell	MW/year	25k (16k – 36k)	58k (39k – 82k)	20
Module	MW/year	11k (6.0k – 38k)	24k (13k – 38k)	20

Maintenance costs were assumed 3% of capital cost per year.

Land was not included as a capital cost, instead a land (excl building) rental rate of USD 10 / sqm / year and USD 20 / sqm / year was assumed for China and Australia respectively.

Labour Headcount and Costs

	Capacity Unit	Headcount CN (#/Capacity Unit)	Headcount AU (#/Capacity Unit)
Poly-Si	Tonne/year	0.017 (0.014 – 0.021)	0.021 (0.017 – 0.025)
Ingot + Wafer	MW/year	0.16 (0.12 – 0.19)	0.19 (0.15 – 0.22)
Cell	MW/year	0.20 (0.16 – 0.24)	0.24 (0.19 – 0.29)
Module	MW/year	0.21 (0.17 – 0.26)	0.26 (0.20 – 0.31)

Labour headcount was assumed 20% higher in Australia than China due to inefficiencies at smaller scale, shorter typical working hours and lower manufacturing experience of the workforce. Labour costs per person were assumed 4x the cost in Australia compared to China.

Energy Usage and Cost

Sector (Prod Unit)	Energy Type	Usage (kWh / Prod unit)	Median usage (kWh/W)	CN Energy Cost (USD/MWh)	AU Energy Cost (USD/MWh)
Poly-Si (kg poly)	Electricity	49 (45 – 60)	0.123	60 (50 – 70)	65 (52 – 78)
	Steam	7.7 (6.7 – 8.7)	0.019	60 (50 – 70)	56 (52 – 78)
Ingot + Wafer (m^2 of wafer)	Electricity	15 (14 – 16)	0.065	60 (50 – 70)	90 (80 -100)
Cell (m^2 of cell)	Electricity	10 (9.2 – 12)	0.045	60 (50 – 70)	90 (80 -100)
Module (2 m^2 size)	Electricity	5.0 (4.0 – 6.0)	0.012	60 (50 – 70)	90 (80 -100)

Energy usage ranges are given in the table above per production unit (kWh/production unit). For ease of comparison, the median energy usage in kWh/W of each sector is also provided.

The delivered cost of electricity in China and Australia is difficult to estimate due to variations over time, specific location, the source of the electricity and government incentives. Although subsidised electricity prices in China can be very low (reportedly 20 USD/MWh), our assumption assumes more recent estimates for industrial users. For Australian poly-silicon production (which is very electricity price sensitive), we assume the lowest range of electricity futures pricing, plus an estimate of network charges. For the other sectors we assume higher pricing.

Material Costs

Sector	Significant Materials assessed	AU Cost increase	Other Trade Costs
Poly-Si	mg-Si, Filaments	10-20% 10-20%	55% Tariff
Ingot + Wafer	Crucible Graphite Heater Argon Diamond Wire Coolant	10-20% 10-20% 50-150% 10-20% 50-150%	

Cell	Silver Paste TMA[175] Other Chemicals	10-20% 50-150% 50-150%	17% lost incentive
Module	Glass, Frame, Backsheet, EVA, J-box, Ribbons, Silicone	All 10-20%	

Based on feedback from stakeholders, we assume that an Australian factory importing non-chemical materials from the China supply chain would have to pay 10-20% more than a typical Chinese factory due to the smaller scale of production in Australia. For chemical materials imported from China, the estimate was 50-150% more than a typical Chinese factory because chemical costs are much higher once exported outside of China due to transport safety and the need for local storage, distribution and regular delivery services. These higher costs are in addition to any international shipping and import tariffs.

Shipping Costs

We estimated the total mass of input materials needed to be imported per sector, and estimated international shipping to be 8.0 (6.7-9.6) USc/kg.

We do not estimate national shipping costs such as China material supplier to China factory location (for China based production) or China material supplier to export port and import port to Australian factory location (for Australia based production). These additional costs are very site specific.

Overhead Costs

Other non-production related costs such as Research and Development, Sales, General and Administration were assumed to be an additional 13% of all other costs for both China and Australia.

Working Capital

Cash and financing required for purchasing materials and incurred operating expenses before receiving cash from sales is not included in this model.

Model Outputs

Separate models were built for Poly-Si, Ingot/Wafer, Cell and Module, with the outputs shown in the main sections of the report. For each sector, the cost was estimated for a unit of production, which can be converted into a cost in USD/W or AUD/W based on an assumed power per unit. The costs calculated for each sector are the CONVERSION costs, and do not include the cost of the previous sector.

[175] TMA = Tri-methyl Aluminium

Sector	Unit of Production Modelled	Conversion cost does not include	Assumed power (W/unit of production)
Poly-Si	kg poly-Si		400
Ingot + Wafer	m^2 of wafer	Cost of Poly-Si	230
Cell	m^2 of cell	Cost of Wafer	230
Module	One 2 m^2 module	Cost of Cell	400

The calculated cost outputs are estimates of production costs, not selling price. Actual selling price will be impacted by market forces and for a sustainable business would need to be higher to account for financing, tax and profits.

Pie charts (e.g., Figure 3-2 and Figure 3-3 for poly-Si) – show the total estimated cost (centre), and the percentage contributions of the main cost components (median value from the cost model).

Stacked bar charts (e.g., Figure 3-4 poly-Si) –show the detailed contribution to the cost estimate by category. The error bars show the uncertainty in the calculations due to ranges in input parameters.

To better visualize the uncertainties in the output of the bottom-up cost model, the output of the Monte Carlo analysis is shown in Figure A-1 for each sector. What is displayed is a histogram of the 5000 Monte Carlo iterations. As an example of how to interpret these, we can look at the poly-Si production cost. For the Blue histogram (China based production), the peak (~ 9 USD/kg) indicates the most likely production cost, the bulk of the iterations are between 8 and 10 USD/kg, but there are some unlikely cases that are higher or lower than this bound. For the Orange histogram (Australia based production), the cost is likely between 15 and 18 USD/kg.

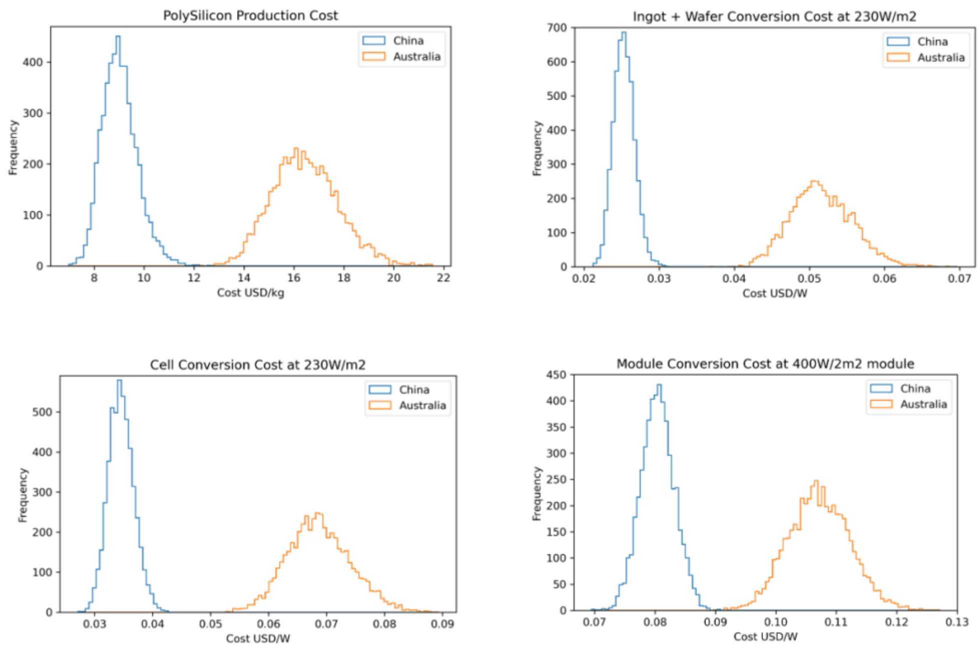


Figure A 1: Uncertainties around costs in each sector

Table of data used in Figure 3-4 – cost in USD/kg of poly-Si

Cost Category	China	Australia
Overheads	1.0 (0.93 - 1.1)	1.9 (1.7 - 2.1)
Land	0.12 (0.1 - 0.14)	0.24 (0.2 - 0.29)
Maintenance	0.37 (0.3 - 0.45)	1.1 (0.91 - 1.4)
Depreciation	1.1 (0.85 - 1.3)	3.2 (2.6 - 4.0)
Labour	0.3 (0.22 - 0.39)	1.4 (1.1 - 1.8)
Other Utilities	0.46 (0.37 - 0.57)	0.49 (0.39 - 0.63)
Electricity	3.0 (2.4 - 3.8)	3.3 (2.5 - 4.2)
Shipping	0	0.25 (0.21 - 0.3)
Tariff/Subsidy	0	1.5 (1.2 - 1.7)
Materials	2.6 (2.3 - 2.8)	2.9 (2.6 - 3.4)

Table of data used in Figure 3-9 – Conversion cost of Ingot/Wafer (excluding poly-Si) in USD c/W

Cost Category	China	Australia
Overheads	0.29 (0.27 - 0.31)	0.59 (0.53 - 0.66)
Land	0.017 (0.014 - 0.019)	0.033 (0.029 - 0.038)
Maintenance	0.11 (0.09 - 0.14)	0.24 (0.2 - 0.3)
Depreciation	0.37 (0.3 - 0.46)	0.77 (0.62 - 0.95)
Labour	0.26 (0.2 - 0.34)	1.2 (0.93 - 1.6)
Electricity	0.39 (0.32 - 0.47)	0.59 (0.51 - 0.67)
Shipping	0	0.12 (0.1 - 0.15)
Tarriff/Subsidy	0	0
Materials	1.1 (1.0 - 1.1)	1.5 (1.3 - 1.8)

Table of data used in Figure 3-15 – Conversion cost of Cell (excluding wafers) in USD c/W

Cost Category	China	Australia
Overheads	0.4 (0.37 - 0.43)	0.79 (0.71 - 0.88)
Land	0.024 (0.019 - 0.029)	0.048 (0.038 - 0.057)
Maintenance	0.15 (0.11 - 0.18)	0.31 (0.25 - 0.39)
Depreciation	0.61 (0.48 - 0.76)	1.2 (1.0 - 1.6)
Labour	0.33 (0.25 - 0.43)	1.6 (1.2 - 2.1)
Electricity	0.27 (0.22 - 0.33)	0.4 (0.34 - 0.47)
Shipping	0	0.11 (0.09 - 0.13)
Tarriff/Subsidy	0	0.3 (0.26 - 0.34)
Materials	1.7 (1.5 - 1.8)	2.0 (1.8 - 2.3)

Table of data used in Figure 3-21 – Conversion cost of modules (excluding cells) in USD c/W

Cost Category	China	Australia
Overheads	0.93 (0.89 - 0.97)	1.2 (1.2 - 1.3)
Land	0.0075 (0.005 - 0.01)	0.015 (0.01 - 0.02)
Maintenance	0.029 (0.02 - 0.039)	0.059 (0.042 - 0.081)
Depreciation	0.11 (0.083 - 0.13)	0.22 (0.17 - 0.27)
Labour	0.18 (0.14 - 0.24)	0.88 (0.66 - 1.1)
Electricity	0.074 (0.056 - 0.095)	0.11 (0.087 - 0.14)
Shipping	0	0.45 (0.37 - 0.53)
Tarriff/Subsidy	0	0
Materials	6.7 (6.4 - 7.0)	7.7 (7.2 - 8.3)

Appendix B: Levelised Cost Of Production Assessment Assumptions

Summary

The quantitative policy assessment in this report is based on a calculation of the levelised cost of production (LCOP) at each step of the PV value chain in Australia. LCOP is a form of discounted cash flow analysis that provides the average per unit cost of production in present value terms over a defined production period. In other words, the LCOP is the cost of producing a unit of production, including the financing costs (i.e., the return expected from debt and equity investors) over a fixed production period.

The LCOP in Australia is compared against an assumed market price or 'Cost of Importing' the product from China. The difference between the LCOP and the 'Cost of Importing' is used to identify the cost gap that would need to be bridged for an Australian industry to be competitive with imported products. Different policy levers are applied to estimate the impact on the cost gap across each step of the value chain. This provides an assessment of how effective each policy lever is in closing the cost gap at each step of the value chain, as well as the estimated associated cost to government over the production period.

LCOP Model Assumptions

LCOP input assumptions

The LCOP is calculated using the median (50th percentile) values of the bottom-up, techno-economic cost of conversion analysis to approximate the cost of production in Australia (see Appendix A for further detail).

Each step of the value chain is assessed in isolation from the other steps of the value chain to assess the viability of a manufacturing facility at each step. Consequently, all input materials are assumed to be sourced from China, as some input materials do not have existing production capabilities in Australia and would require additional investment and time to scale up sufficiently.

For the ingot/wafer, cell and module steps of the value chain, the required input materials from the preceding value chain step(s) are also assumed to have been sourced from China. The cost of the preceding value chain step is calculated in the same way as the 'Cost of Importing' of the previous value chain step (see below), with a 15% premium applied to account for the reduced purchasing power of an Australian company.

Key parameter assumptions are outlined below:

Parameter	Assumption	Comment
Industry WACC	10%	This is deemed to be representative for a facility in a nascent industry, based on consultation with a range of business modelling and financial experts. The industry WACC is used as the discount rate for the purposes of calculating the LCOP.
Government Discount Rate	7%	Used to calculate the total support required (total cost to government) of each policy lever. This is based on typical values used in business cases for government.
Initial Capital Expenditure	All spend is incurred in Year 0	-
Sustaining Capital Expenditure	Separate expense from annual maintenance spending	Sustaining capital expenditure (i.e., the cost to replace equipment) is incurred in the year after the initial capital equipment has fully depreciated. Maintenance is a distinct and separate cost category in the model. Sustaining capex is assumed to be 100% debt funded.
Debt-to-equity ratio	60:40	Used for the purpose of calculating the financing arrangement for the upfront capital expenditure.
Commercial Loan Interest Rate	10%	For debt related financing, a conservative commercial loan interest rate of 10% was applied, based on consultation with a range of business modelling and financial experts and the assumed risk profile of a nascent industry.
Commercial Loan Term	5 years	-
Cost / Price Growth Rates	None	No cost/price growth rates have been factored into the analysis. Price growth rates would likely be counteracted with learning rates and automation, therefore for simplicity they are assumed to balance across the assessment period.

Cost of importing

The 'Cost of importing' is an assumption made on the estimated cost of importing the comparable product from China in present value terms. Given that there is currently no existing market in Australia for poly-Si, ingots/wafers and cells, and spot prices globally have shown significant variation over time, the market price is calculated based on bottom-up Chinese cost of production (in 2023 real dollar terms) and applying the following assumptions:

- The techno-economic cost of production in China in real 2023 dollars is used as a baseline (see Appendix A for further detail).
- a 10% margin to approximate the unknown financing, cost of capital and profit that would be realised by Chinese producers at the poly-Si, ingot/wafer and cell stage.

- a 5% margin to approximate the unknown financing, cost of capital and profit that would be realised by Chinese producers at the module stage.[176]
- the cost of transport of the product from China to Australia.

Policy Lever Assumptions

Across each step of the value chain, a series of policy levers are applied to test their impact on closing the cost gap. For each policy lever, the % reduction of the cost gap is calculated to determine the efficiency of the policy lever, as well as the overall (discounted) cost to government to determine the required level of support from government.

The following table outlines key assumptions applied for select policy levers:

Policy Lever	Definition	Analysis Method	Duration
Production credit	Variable operating cost reduction applied on a per unit of production basis	Sized to match the IRA Sized to match the cost gap (either in isolation or in conjunction with other policy levers)	First 10 years of production
Concessional Loan	Share of initial project debt at a concessional rate	Low (0%), medium (4%) and high (8%) interest rate on 60% of total upfront CAPEX spend (assumes 100% of the debt is serviced via the concessional loan)	Loan term of 5 years
Capital Grant	One-off upfront grant to reduce initial capital expenditure	Low (25%), medium (50%) and high (100%) grant sized to match upfront CAPEX spend	N/A
Reduced Electricity Charge	Reduction in the electricity operating cost	Low (USD30/MWh), medium (USD45/MWh) and high (USD60/MWh) fixed electricity price guarantee	First 10 years of production

[176] A 5% margin was applied at the module step due to the significantly lower capital intensity of a module facility, and hence lower financing and cost of capital requirements compared to the other steps, as well as stakeholder feedback from Chinese companies on realistic profit margins.

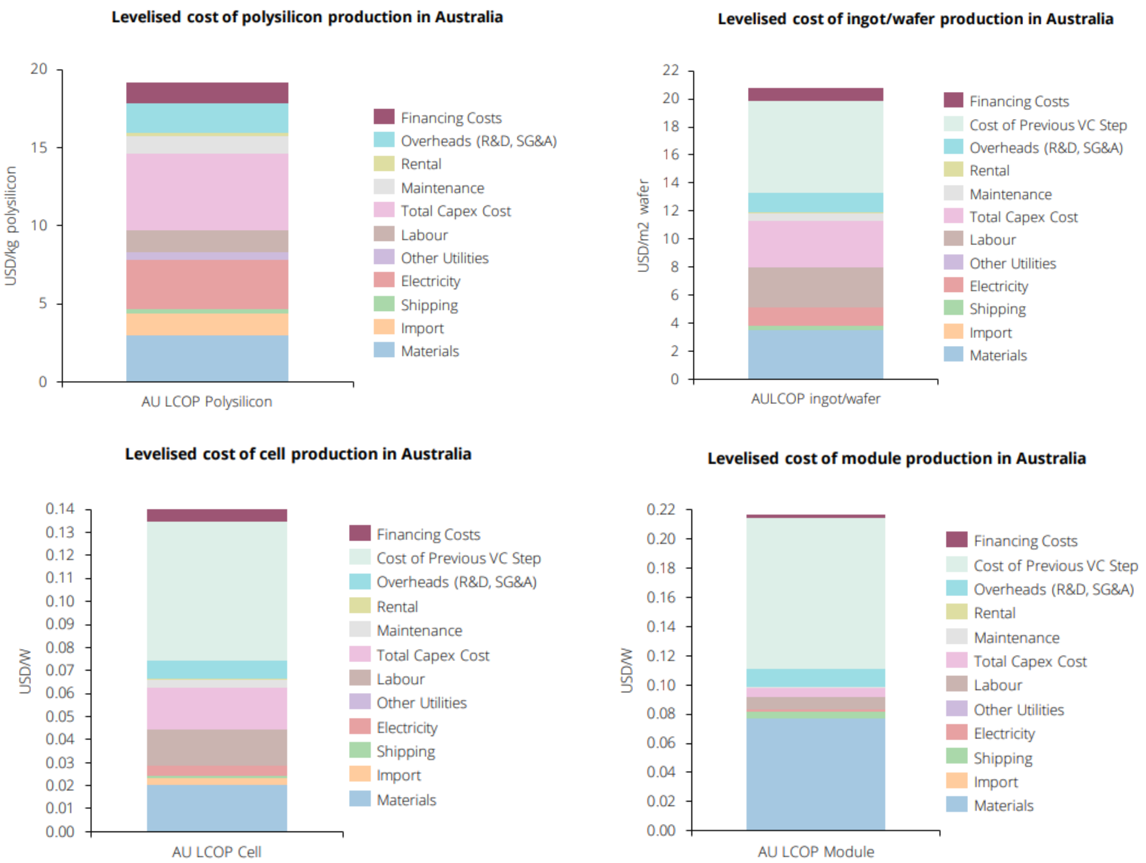


Figure A 2: Levelised cost of production (LCOP) in Australia across the value chain.

Appendix C: Policy assessment – Long List

	Policy Lever	Mechanism
ENABLING	Streamlined permitting and approvals	Streamlined / accelerated approval process, e.g., through 'major project' status, for facility construction and equipment certification
	Reskilling support	National or sub-national funds / subsidised training to educate skilled labour for solar PV manufacturing
	Targeted visas	Attractive visa options for foreign workers, measures focussed on bridging / permanent residency visas for skilled foreign workers
	Foreign investment guidelines	Clear guidelines outlining acceptable parameters for international investment, including through partnerships and joint ventures
DEMAND	Local-content requirements and incentives	Local-content incentives (such as financial premiums or preferential selection) or requirements for domestically manufactured solar PV products attached to policies stimulating solar PV development and installation
	Auctions/tenders	Solar PV power plant auctions/tenders linked to commissioning new manufacturing facilities
	Government procurement guarantees	Ensuring guaranteed annual minimum procurement (for government buildings / projects)
	Solar rebates	Financial incentive reducing the upfront cost of installing a solar system
	Feed-in Tariffs (FIT)	Offering guaranteed above-market prices to solar energy producers for what they deliver to the grid
	Low-cost financing	Low-cost financing for individuals or businesses installing domestically manufactured solar PV products
	Solar module mandates	Government regulation mandating the installation of solar modules for businesses/governmental bodies/citizens/etc. when a specific condition is met, such as when constructing a new building, or meeting a specific energy consumption
	Government warranty guarantees	Government providing a form of warranty or insurance for locally produced modules
	International partnerships	Agreements and partnerships with countries / companies to build out PV supply chain
	Legislation encouraging low-carbon/ESG transparent products	Transparency and ESG reporting obligations
	Anti-dumping regulations	Anti-dumping duties or countervailing duties imposed by the Federal Government on imported projects which have been found through a rigorous process to cause material injury to Australian industry

	Import bans	Import bans on solar PV products not meeting certain ESG standards or regulations, to set standards for imported PV products and equipment
	Import standards: Carbon tax	Border CO_2e/ tax adjustments (carbon border adjustment mechanisms) for imported solar PV products
	Carbon footprint standard	Carbon footprint standard for modules in tenders
	Eco-labelling	Label indicating quality of the product and that it meets the highest-environmental standards
SUPPLY	Production-linked support	Subsidies to reduce operational costs. Can be linked to achieved production and sales (production-linked support), which can be granted as a direct payment or an inflation-adjusted tax credit per unit (module, cell, etc.) produced.
	Investment tax credit	Tax credits for constructing one or multiple solar PV supply chain segment manufacturing facilities
	Low-income bonus	Bonus subsidy/credit when facility is located within low-income community
	Energy community bonus	Bonus subsidy/credit when facility is located within a community whose economy is reliant on fossil-fuel production and therefore affected by the energy transition
	CAPEX support: capital grant/subsidies	Direct upfront payment to cover land and infrastructure costs
	Concessional finance	Government financial support.t such as guarantees, loans or equity provided at concessional terms compared to commercial lenders, for greenfield solar PV manufacturing facilities, or for their expansion or operation
	Electricity price guarantees or reduced electricity charges (network fees, GST, etc.)	Lower or guaranteed energy prices for energy-intensive PV manufacturing facilities through network charge concessions, contracts for difference, etc.
	Utility subsidies	Subsidies for utility consumption (water, electricity, etc.)
	Infrastructure rebates	Subsidies to cover costs for a company of connecting to shared infrastructure or building new infrastructure
	Concessional land/leases	Leases provided at rates lower than market value
	Temporary tax reductions: Reduced income tax rates	Lower income tax rates for solar PV manufacturing companies
	Reduced import tariffs on equipment	Lower import tariffs for imported manufacturing equipment and material inputs
	Temporary tax reductions: Reduced GST rates	Lower GST rates for imported manufacturing equipment and material inputs
	Labour subsidies	Government financial support to reduce labour costs through lower charges or payroll tax exemptions
	R&D Funds	R&D and innovation funds, or funds for academics and the private sector to develop solar PV technologies

	Government infrastructure investment	Government investment to upgrade infrastructure, such as logistics, waste management and power
	Special Economic Zone (SEZ)	Area that has different economic regulations than elsewhere in the same country to encourage businesses to set up in the zone. Examples: free-trade zones (area with no customs duties or taxes), industrial hubs (area where infrastructure and facilities are provided)

Note: Long-list informed by IEA reports, industry and government stakeholder engagement, existing Australian/international policy, internal Deloitte knowledge

Appendix D: Demand Levers to Create a Level-playing Field for the Domestic Market

Concerns were raised by stakeholders during engagement about creating a level playing field for the domestic market. Companies identified they would require reassurance from the Australian government that a local manufacturing industry would be protected in case of future market tactics by established international players. Levers creating a level-playing field for the domestic market might have a role to play following successful establishment of a domestic industry, to protect domestic solar PV manufacturing in Australia in the long-term. They can also be adopted to limit certain practices (such as modern slavery or unsustainable manufacturing practices). Import standards and anti-dumping regulation are not put forward in the final recommendations, as these policy measures have a higher risk of decreased economic efficiencies, retaliatory action and trade disputes. The assessment below discusses international case studies.

Import Standards

Import standards and restrictions are adopted by governments to create a level-playing field for the domestic industry and support them from unfair or harmful competition from foreign suppliers. Examples include supply chain transparency obligations or mandating environmental standards.

To address human rights violation allegations in the Xinjiang Uyghur Autonomous Region of China, the US has introduced the Uyghur Forced Labor Prevention Act, which prohibits the imports of goods made with forced labour *(see case study)*. Due to supply chain concentration, the global solar industry is very dependent on Xinjiang for imports, especially for poly-Si. The impacts of the regulation on US solar PV manufacturers and developers have therefore been mixed. On one hand, the restriction has created high uncertainty for US-based companies to be able to access products from China, as shipments can be delayed or detained. US companies have warned that the regulation limits solar PV development due to its constraints on solar panel access, a concern that has been raised by downstream Australian stakeholders as well. On the other hand, the regulation has prompted solar PV players to diversify supply sources, which have created investment opportunities for domestic manufacturers.

Case Study: US – Bill of Materials (BOM) transparency requirement[177]

The US's Uyghur Forced Labor Prevention Act (UFLPA), entered into force on **June 21 2022,** includes stricter import **prohibitions** against goods made with forced labour.

Entry of products classified on the "UFLPA Entity List" (products coming from regions presumed to be made by forced labour) within the US is prohibited. US Border and Customs Protection can confiscate the goods.

The responsibility lies with the importer to provide "clear and convincing evidence" that products were not produced using forced labour.

Types of information required can include:

- **Due diligence system information** (e.g., supplier engagement, code of conduct, mapping, training, monitoring).
- **Supply chain tracing information** from raw materials to imported goods.
- **Supply chain management measures** (e.g., an importer's internal controls and operating system).
- **Evidence** that imported goods were not made with forced labour (e.g., worker information at each stage of production, evidence that workers were recruited and worked voluntarily, labour audits, wage payment,etc.)

The EU Carbon Border Adjustment Mechanism (EU CBAM) was recently put in place to ensure the EU's climate goals are not jeopardised by the imports of goods that are higher in emissions intensity, coming from countries with less ambitious climate regulation *(see case study)*. The CBAM ensures a level playing field for domestic producers that pay a carbon price under the EU ETS, by imposing a carbon tariff on imports where a carbon price has not been paid in the country of production. At the moment, solar PV products will not be covered by the EU CBAM, however this might change in the future. Similarly, The Canadian Government has begun to research the implications of introducing Border Carbon Adjustments (BCAs), which would require imports to meet the same emissions pricing as locally produced products, to prevent carbon leakage and ensure global competitiveness of Canadian products. However, no policy has been put forth yet.[178]

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[177] Department of Homeland Security, "Uyghur Forced Labor Prevention Act", 2023.
[178] Government of Canada, https://www.canada.ca/en/department-finance/programs/consultations/2021/border-carbon-adjustments/exploring-border-carbon-adjustments-canada.html, viewed 24 Oct 2023.

Case Study: EU – Carbon tariff in the Carbon Border Adjustment Mechanism (CBAM)[179]

The EU's carbon border adjustment mechanism (CBAM) is a policy tool aimed at **pricing the carbon emissions** associated with the production of carbon-intensive **goods entering the EU**. Its primary objective is to promote cleaner industrial production in non-EU countries and **ensure a level playing field for domestic industries that pay a carbon price under the EU Emissions Trading Scheme (EU ETS)**. The EU Emissions Trading System (EU ETS) is a market mechanism that caps emissions from high-emitting industries in the EU and distributes allowances. Companies whose emissions are below the cap can sell excess allowances, while those over must purchase additional allowances.

The CBAM operates by ensuring that imported goods in **industries covered by the mechanism (aluminium, cement, iron, steel, electricity, hydrogen and fertilisers)** have paid a price for the carbon emissions embedded in their production processes, **equivalent to the carbon price** applied to domestic production **within the EU**.

EU importers will be required to **declare** the quantity of goods imported in the preceding year and their **associated greenhouse gas (GHG) emissions**. Importers will then need to **purchase** a corresponding number of CBAM **certificates**. If they can provide verified information from third-country producers demonstrating that a carbon price has already been paid during the production process of the imported goods, they can deduct the corresponding amount from their final bill.

The permanent system will enter into force from 1 **January 2026 onwards**. The EU carbon price on 26 May 2023 was equal to 85.5 EUR/t CO_2e (record price to date: 100 EUR/t CO_2e Jan 2023).

Import standards have been adopted in other jurisdictions to create a level playing field for their existing domestic industries and ensure competitiveness of locally produced products. To ensure success in these markets, Australian producers must make sure they comply with these standards. Compared to other international PV producers (such as China and Southeast Asia, depending on the region of production), Australia might even have a competitive advantage in the US and EU markets if it guarantees sustainably produced low-carbon products and is one of the fastest players in doing so.

Import standards are not recommended in this report as an immediate policy measure for solar PV development in Australia, as they do not directly contribute to the predefined objective of setting up domestic solar PV capacity in a timely manner. Import standards need to be introduced over time to allow industry to adapt and are not appropriate in countries where industry does not yet exist. Additionally, import standards and regulation are in general very cumbersome for both government

[179] European Commission, https://taxation-customs.ec.europa.eu/system/files/2023-05/20230510%20CBAM%20factsheet.pdf, viewed 24 Oct 2023.

and companies, to comply with on one hand and to control on the other, which increases cost and complexity of trade. Additionally, it is important to note that import standards such as import restrictions and carbon tariffs may trigger retaliatory action from international trade partners.

However, in the long term, following full establishment of a mature industry, Australia could consider import standards to create a level-playing field for the domestic industry if relevant. Australia could design a carbon border adjustment mechanism which places carbon tariffs on imported goods and ensure solar PV manufacturing is part of the covered industries. Success of a CBAM will depend on the Australian player's ability to source clean energy for its operations. Australia could also mandate supply chain transparency reporting obligations for companies importing solar PV inputs such as poly-Si. Similar to carbon taxes, the effectiveness of supply chain transparency obligations to protect domestic industry is dependent on the domestic industry's ability to meet the transparency obligations.

Anti-dumping Regulation

Anti-dumping laws refer to regulations and measures implemented by governments to address the unfair trade practices of dumping (foreign producers flooding the domestic market with products at artificially low prices). Measures include anti-dumping duties or import-tariffs. Concerns were raised by stakeholders, with companies identifying they would require reassurance from the Australian government that a local manufacturing industry would be protected in case of future market tactics by established international players.

In Australia, the Anti-Dumping Commission is responsible for conducting assessments of anti-dumping claims, which constitutes a long and thorough process. Anti-dumping cases have been filed by the solar manufacturing industry *(see case study)*, however with limited impact as cases are difficult to prove. A 55.5% import tariff is currently in place on metallurgical silicon imports from China, following a successful complaint by Australian smelter Simcoa.

Case Study: Australia – Anti-dumping measures in solar PV

PV module dumping allegations against China:

Tindo Solar lodged a complaint against alleged Chinese dumping of PV modules and panels in 2014, claiming to have suffered volume injury. While evidence of PV dumping was found, the Anti-Dumping Commission stated that the impact of this dumping on local industry was negligible and terminated investigation in November of 2015. The investigation was briefly reopened in 2016 but was terminated again for having negligible impact on Australian industry.

Shaped aluminium dumping from Vietnam and Malaysia:

Capral submitted a complaint about shaped aluminium exports from Vietnam and Malaysia in FY17, which caused the Anti-Dumping Commission to impose an anti-dumping duty of 1.9% on Vietnamese products and 3.24% on Malaysian products after finding that dumping was occurring and there was material injury. However, this duty was concluded in 2022 after it was found that Vietnam and Malaysia only accounted for a small percentage of Australia's shaped aluminium imports. This decision is currently under review.

Metallurgical silicon dumping and subsidisation from China:

Simcoa lodged a complaint against Chinese silicon metal in 2013, alleging dumping and subsidisation. Investigation found dumping margins of upwards of 18% and subsidisation margins of up to 37.6%, and that this has caused material injury to the Australian industry. A duty of 55.5% was imposed on all silicon metal imports from China. This duty underwent review in 2019, where it was decided that the measure should remain in place.

The case studies from India and Türkiye demonstrate that tariffs lead to higher prices for consumers while having a minimal effect on increasing domestic production. Higher prices can reduce the number of solar projects being developed and therefore slow the pace of the energy transition.

Case Study: India & Türkiye: Import tariffs[180]

Between 2010-2017, India and Türkiye were able to **slightly grow domestic solar manufacturing** (12 GW and 7 GW of module assembly capacity respectively), by **encouraging demand through local content incentives and requirements**.

Following the establishment of their respective small manufacturing bases, both countries implemented anti-dumping measures on cells and modules imported from China.

In 2017, Türkiye established an **anti-dumping fee of 20 USD/m^2** on Chinese-based PV panel manufacturers. India on the other hand implemented a safeguard duty **of 25% on PV modules and cells** from China, Malaysia and Taiwan in 2018.

These anti-dumping measures had adverse effects on the domestic market, however. Instead of fostering growth of domestic cell manufacturing, these measures lead to increased local prices, primarily because of insufficient existing cell-manufacturing capabilities.

Sources: IEA, Special Report on Global PV Supply Chains (2022)

Special Report on Solar PV Global Supply Chains

Additionally, tariffs on one section of the supply chain can negatively impact others: e.g., tariffs on cells for a module producer, tariffs on modules for an assembler, etc. The US case study proves that tariffs on Chinese solar panels have been detrimental for American solar panel assemblers and installers. Additionally, US tariffs on Chinese PV panels led to retaliatory action from China on US-produced poly-Si during the 2010s, which effectively drove the American poly-Si producers out of business.

[180] IEA, "Special Report on Solar PV Global Supply Chains", August 2022.

Case Study: US – Anti-dumping tariffs

The US has been imposing anti-dumping tariffs and import duties on PV equipment from China since 2012 and broadened measures to other countries in Southeast Asia in the years after. While the measures were expected to result in increased domestic supply, they have had mixed outcomes.

The section 201 tariff, imposed by Trump in 2018, is a tariff on solar cells and panels imported into the US that do not meet exemption status. The tariffs started at 30% in 2018, and ramped down to 25% in 2019, 20% in 2020 and 15% in 2021. While there is evidence that the tariffs led to increased domestic cell assembly, a study from the Solar Energy Industries Association calculated that the tariffs have led to the loss of more than 62,000 US jobs and 19bn USD in new private sector investment. Especially the sector of solar installers was severely hit, as PV panels became uncompetitive because of the tariffs. The industry claimed the tariffs also created a slow down on solar projects, delaying the energy transition. Tariffs can also lead to retaliatory action. For example, China imposed tariffs as high as 57% on US-produced poly-Si in China following the US tariffs, effectively leading to a reduced US market share of global poly-Si production.

In 2022, the Biden administration decided the US will impose new duties on some major Chinese solar producers from 2024 onwards.

Anti-dumping practices are difficult to prove and possible to circumvent, and only sensible if there is an existing domestic market. Anti-dumping cases are a costly and complicated process, with no certainty of outcomes. Anti-dumping measures are not a lever government can directly pull to achieve the policy objective and shouldn't be prioritised.

Additionally, tariffs create investment uncertainty for players in the solar industry, leading to loss of investment and jobs, but have other undesirable outcomes as well, such as increased prices for consumers and slowing the pace of the energy transition due to less and/or delayed solar projects. International case studies from the US, India and Türkiye demonstrate that tariffs on one section of the supply chain can impact the other and create possible retaliatory action and trade disputes, while having a minimal effect on increasing domestic production.

Appendix E: Other Supply-side Levers: Temporary Tax Reductions

Other forms of support, such as temporary tax reductions, have been adopted by other jurisdictions to temporarily temper the operational costs of solar PV manufacturers. Australia has an R&D tax credit in place that allows companies investing in research and development to reduce their tax liability.

In Canada, manufacturers of "zero-emission technologies", which includes manufacturing of solar PV panels, qualify for a temporary income tax rate reduction.

Case Study: Canada – Corporate tax rate reduction for zero-emission technology manufacturers

In Canada, manufacturers of "zero-emission technologies", which includes the manufacturing of solar PV panels (= manufacturing of energy conversion equipment), qualify for a temporary income tax rate reduction.

The measure is available for tax years **starting after 2021**, a **reduced rate of 7.5% instead of the otherwise 15%** general corporate income tax will be applied to the manufacturers' profits. For small businesses, the rate is equal to **4.5% instead of 9%**. The reduced rates were initially to be phased out between 2029-2031 but have been **extended** until **2034. They will be gradually phased out from tax years that begin in 2032, after which they will return to normal levels from tax years that begin after 2034.**

A company qualifies as a zero-emission technology manufacturer or processor **if it derives at least 10% of its gross revenue** from all active businesses carried on in Canada from qualified zero-emission technology manufacturing activities.

Specifically **excluded** from the policy support is the manufacturing or processing of **general-purpose parts** or equipment that are suitable for integration into property other than a property listed as an eligible zero-emission technology-related manufactured or processed property.

Source: : 1. Source: : 1.

2. Government of Canada, *https://www.canada.ca/en/revenue-agency/services/tax/businesses/topics/corporations/whats-new-corporations.html*, viewed Dec. 1st 2023.

In China, subsidies and tax exemptions were key in its strategy of building a solar manufacturing industry. Focusing on supply rather than demand creation worked well for China due to the large export market it could tap into. Initially importing equipment allowed China to then develop its own technology and compete with the regions it was once importing equipment from. For critical state-of-the-art equipment such as ingot/wafer technology, Australia could also consider temporary tax exemptions.

Case Study: China – Tax exemptions/reductions on manufacturing equipment[181]

During the early 2000s, China was heavily dependent on imported manufacturing equipment, as most solar PV manufacturing equipment was produced in Europe and the United States at the time.

Solar manufacturers received tax incentives from the Chinese government for imports of solar manufacturing equipment from Europe and the United States. The support phased out once the Chinese producers developed their own equipment.

[181] IEA, "Special Report on Solar PV Global Supply Chains", August 2022.

Appendix F: Competitive Advantage Assessment

The following section outlines a high-level assessment of Australia's competitive advantage compared to other solar manufacturing jurisdictions.

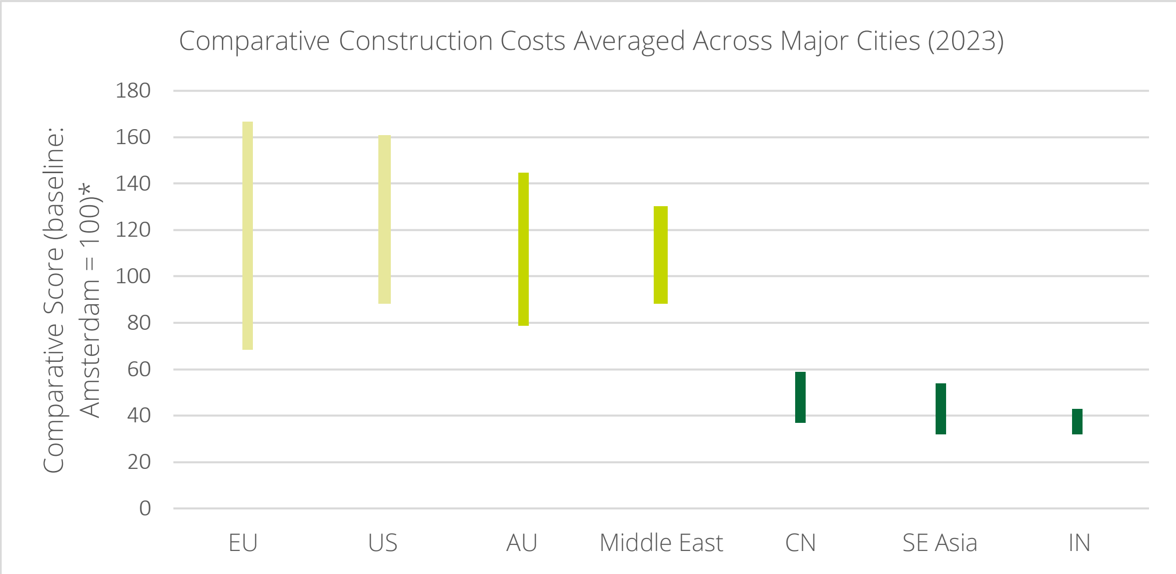
Methodology: each competitive advantage factor is proxied with a chosen metric. Note that ratings for an identified metric are scored on a relative and not absolute basis (with the exception two metrics, availability of quartz & mg-Silicon supply and presence of a domestic glass/aluminium industry). The chosen metric may not fully reflect the factor but is used as a proxy. Regions are proxied with a specific country or an average of different countries in the region. A country is scored with "N/A" (not assessed) when the chosen index source does not include information for the country or region. See sections for specific underlying analysis and sources. AU – Australia; CN – China, SEA – South-east Asia; US – United States, EU – Europe; IN – India; ME – Middle East.

Relative scale

competitive disadvantage → competitive advantage

Factors underpinning competitive advantage		Proxy Metric	Supporting Data	AU	CN	SEA	US	EU	IN	ME
CAPEX	**Construction costs**	*Construction cost index*	F.1.							
ELECTRICITY	**Renewable energy potential**	*Solar potential (specific PV power output)*	F.2.							
	Cost of electricity (current)	*USD/kWh*	F.3.							
	Emissions intensity	*CO_2e/kWh*	F.4.							
DEMAND	**Domestic offtake potential**	*Required annual solar capacity addition to meet targets (GW)*	F.5.							
LABOUR	**Cost of labour**	*Average manufacturing salary (USD/month)*	F.6.						N/A	N/A
	Labour standards	*Qualitative assessment of existing labourpractices*	F.7.							
	Availability of domestic skilled labour	*Manufacturing workers shortage*	F.8.							N/A
	Foreign skilled labour	*Global talent attractiveness*	F.9.		N/A	N/A			N/A	N/A
MATERIALS	**High-quality quartz availability**	*Availability (yes/no)*	F.10.							
	Metallurgical silicon production	*Presence of local industry (yes/announced/no)*	F.10.							
	Domestic aluminium smelting	*Presence of local industry (yes/no)*	F.11.							
	Domestic solar glass industry	*Presence of local industry (yes/announced/no)*	F.11.							
IP	**Strong solar R&D capability**	*Number of dedicated solar research institutions*	F.12.							
	Access to Chinese stateof-the art IP and technology	*Trade relationship with China*	F.13.							
GENERAL	**International investment certainty**	*Ease of doing business index*	F.14.							
	Logistics & export infrastructure	*Logistics performance index*	F.15.							
	Manufacturing expertise	*Economic complexity index*	F.16.							
	Existing policy support	*Case studies and stakeholder engagement*	F.17.			N/A				

CAPEX - Construction Cost



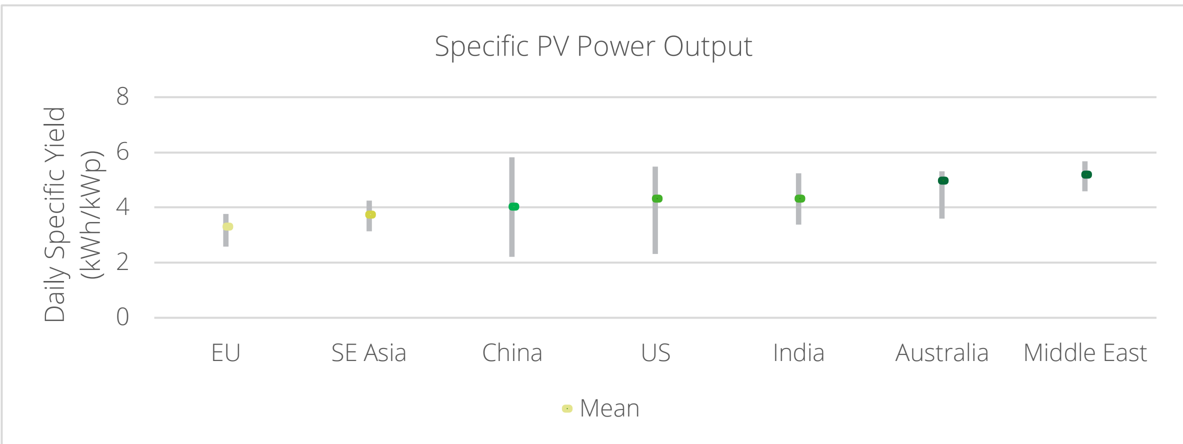
Source: Arcadis, "International Construction Costs 2023", 2023.

Notes: Index is benchmarked to Construction costs in Amsterdam = 100.

Cities used for the minimum and maximum ranges:

- US: Houston (min) - New York City (max).
- EU: Madrid (min) – London (max).
- Australia: Adelaide (min) – Sydney (max).
- Middle East: Dubai (min) – Riyadh (max).
- China: Chengdu (min) – Beijing (max).
- SE Asia: Kuala Lumpur (min) – Bangkok (max).
- India: Bengaluru (min) – Mumbai (max).

Electricity – Renewable Energy Potential

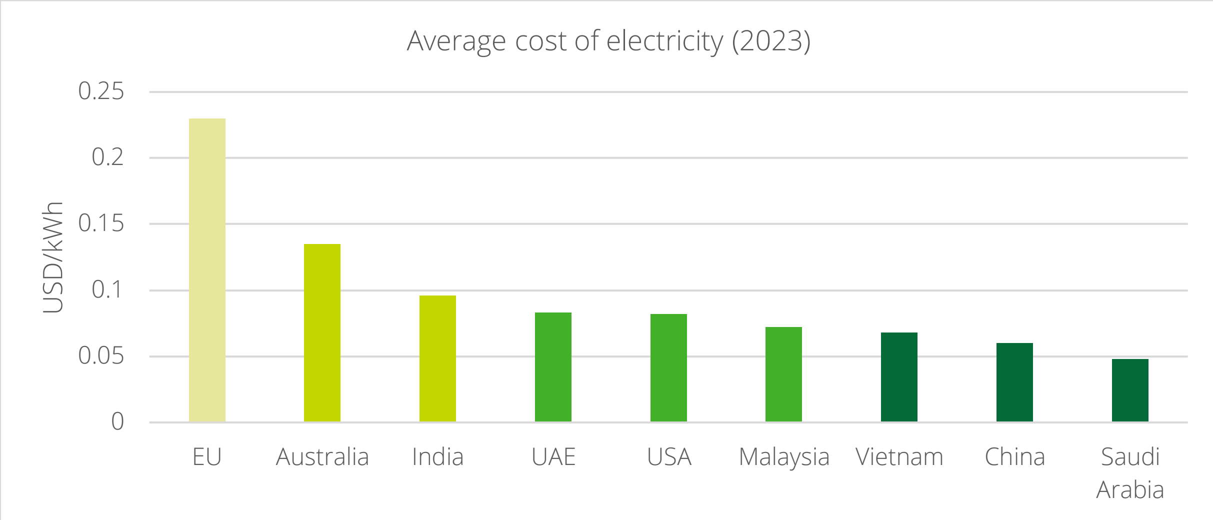


Sources: Solargis, https://globalsolaratlas.info/map, viewed 18 August 2023.

Notes:

- EU is proxied by UK, Germany and Spain.
- SE Asia is proxied by Vietnam, Thailand and Malaysia.

Electricity – Cost of Electricity



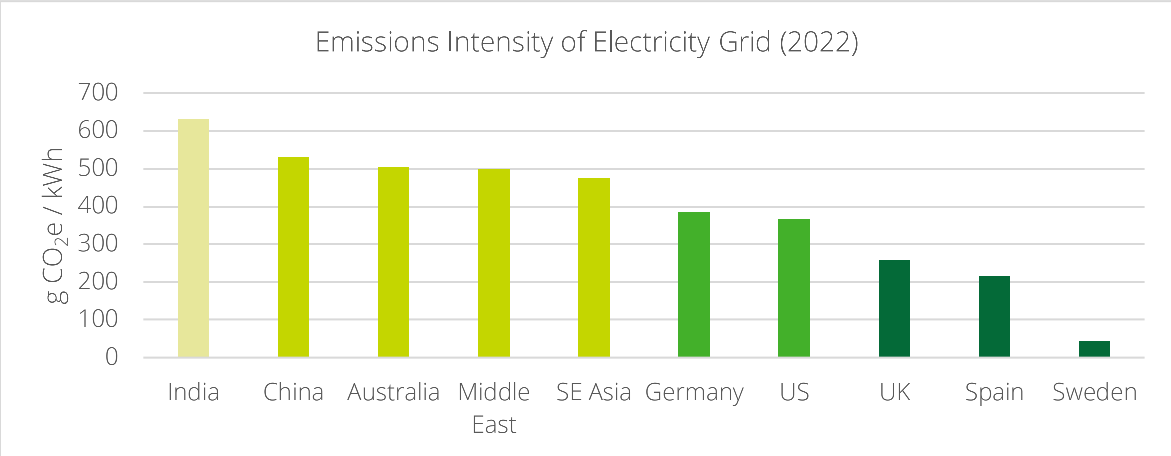
Sources:

- EU: Eurostat, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Electricity_prices_for_non-household_consumers,_second_half_2022_v5.png, viewed 16 Aug 2023.
- Australia: OpenNEM, https://opennem.org.au/energy/nem/?range=7d&interval=30m&view=discrete-time, viewed 16 Aug 2023.
- India: Indian Energy Exchange, https://www.iexindia.com/, viewed 16 Aug 2023.
- Middle East: Dubai Energy & Water Authority, https://www.dewa.gov.ae/en/consumer/billing/slab-tariff, viewed 16 Aug 2023; Saudi Electric Company, https://www.se.com.sa/en/Ourservices/ColumnC/Bills-and-Consumption/ConsumptionTariffs, viewed 16 August 2023.
- US: Energy Information Administration, https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a, viewed 16 Aug 2023.
- SE Asia: Tenaga Nasional Berhad https://www.tnb.com.my/assets/files/Tariff_Rate_Final_01.Jan.2014.pdf, viewed 16 Aug 2023; Vietnam Electricity, https://en.evn.com.vn/d6/gioi-thieu-d/RETAIL-ELECTRICITY-TARIFF-9-28-252.aspx, viewed 16 Aug 2023.
- China: electricity prices gathered from stakeholder interviews

Notes: All values were converted from native currencies to USD.

- EU: average non-household electricity price.
- Australia: average daily price.
- India: Market clearing price.
- Middle East: proxied using UAE industrial tariff averaged across voltage thresholds and Saudi Arabia industrial tariff.
- US: Industrial electricity price.
- SE Asia: Proxied using Malaysia medium-voltage general industrial tariff and Vietnam average non-household tariff.
- China: stakeholder inputs

Electricity – Grid Emissions Intensity



Source: Our World in Data, https://ourworldindata.org/grapher/carbon-intensity-electricity, viewed 18 August 2023.

Notes:

- EU is proxied by UK, Germany, Spain and Sweden.
- SE Asia is proxied by averaging Vietnam, Thailand and Malaysia.
- Middle East is proxied by averaging Saudi Arabia, UAE and Qatar.

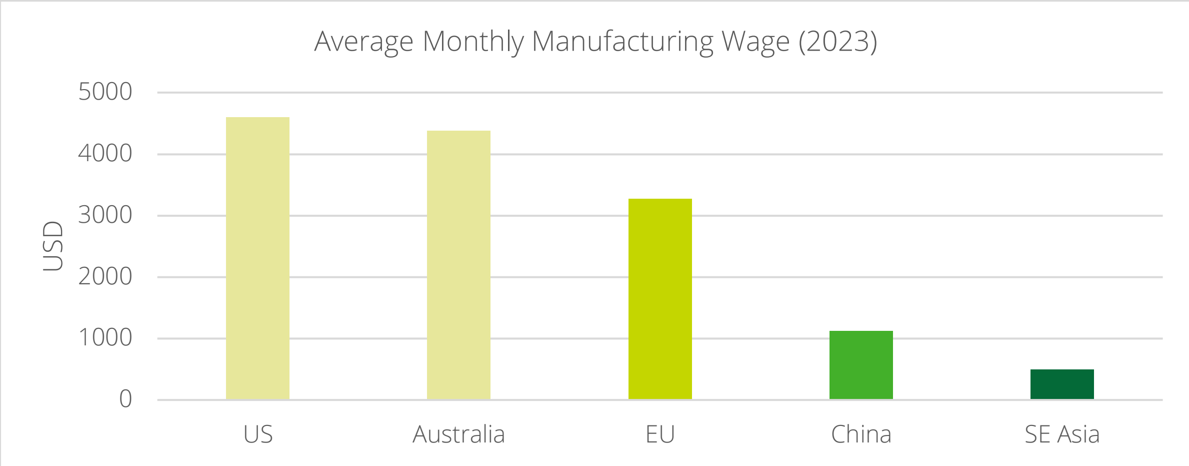
Demand – Domestic Offtake Potential

Notes: Each of the countries/regions (except the US) have published both total current solar capacity in GW and a target solar capacity for a given year. These were then used to calculate how much the country/region must install each year to meet their target given their existing baseline. The US published annual solar capacity installation targets, which were then combined to reach the target total solar capacity installed.

- The Middle East was proxied using the sum of UAE, Saudi Arabia and Bahrain.
- Southeast Asia was proxied using the sum of Thailand, Vietnam and Malaysia.

Country/ Region	Current capacity (GW)	Year of Data Collection	Target Total Installed Capacity (GW)	Target Year	Required annual additional capacity (GW) to meet current political target	Source
China	203	2020	1800	2031	145.2	Environmental Science & Pollution Research, "Forecasting of China's solar PV industry installed capacity and analyzing of employment affect", 19 August 2021.
US	157	2023	330	2030	30 until 2025, and then 60 between 2025-2030	US DOE, https://www.energy.gov/articles/doe-releases-solar-futures-study-providing-blueprint-zero-carbon-grid, viewed 29 Aug 2023. SEIA https://www.seia.org/solar-industry-research-data, viewed 29 Aug 2023.
EU	162	2021	475	2030	34.8	Aurora Energy Research, https://auroraer.com/media/europe-on-track-to-double-solar-capacity-by-2030/, viewed 29 Aug 2023.
India	38	2019	248	2030	19.1	IEA https://iea.blob.core.windows.net/assets/1de6d91e-e23f-4e02-b1fb-51fdd6283b22/India_Energy_Outlook_2021.pdf, viewed 29 Aug 2023.
Middle East	12.21	2023	73.4	2035	5.1	Middle East Solar Industry Association, https://www.mesia.com/wp-content/uploads/2023/01/Mesia-2023-Annual-Report_compressed.pdf, viewed 29 Aug 2023.
Australia	30	2022	70	2030	5	Refere to section 2.1.2 Australian Renewable Energy Target
SE Asia	64.3	2020	80	2030	1.6	IRENA, "Renewable Energy Outlook for ASEAN", 2022.

Labour – Cost of Labour (Manufacturing)



Source: Trading Economics, https://tradingeconomics.com/country-list/wages-in-manufacturing, viewed 2 Sep 2023.

Notes: All wages were converted from native currencies to USD and standardised for one month.

- EU proxied by UK, Sweden and Spain.
- SE Asia proxied by Malaysia, Thailand and Vietnam.
- No data provided in the source for India or Middle Eastern countries.

Labour – Labour, Health and Safety Standards

EU	Forced labour is reported in the manufacturing industry through the UK Modern Slavery Helpline, particularly of migrant workers, though the UK has one of the lowest overall occurrences of modern slavery in the world.
US	Forced labour from prisoners is common in the US as they are exempt from labour law protections. Though a resolution to the Constitution to amend this has been introduced, it has not been made into law. Manufacturing and energy are not high-risk sectors for other forced labour in the US.
AU	While low levels of modern slavery do exist in Australia, manufacturing and energy are not high-risk sectors.
SE ASIA	Forced labour does exist in Thailand's manufacturing sector, typically in the forms of underpayment or restriction of movement of migrant workers. Recent laws have strengthened the rights of migrant workers, though exploitation does still exist.
INDIA	It is estimated that 8 million people are subjected to modern slavery in India, typically in the form of bonded labour. New labour regulations have been introduced to reduce the prevalence of exploitation, though it still exists in some forms. Brick and glass manufacturing are two of the highest-risk industries.
CHINA	Forced labour has been an ongoing problem in the Chinese PV supply chain, particularly in the region of Xinjiang. This has caused the US to introduce the Uyghur Forced Labor
MIDDLE EAST	The infrastructure supporting the 2022 FIFA World Cup hosted in Qatar was found to be constructed using a migrant workforce who allege that they were working in conditions constituting modern slavery, with many worker deaths. Modern slavery claims have been made regarding labour practices in Saudi Arabia where migrant employees require approval from their employers or the government to leave the country.

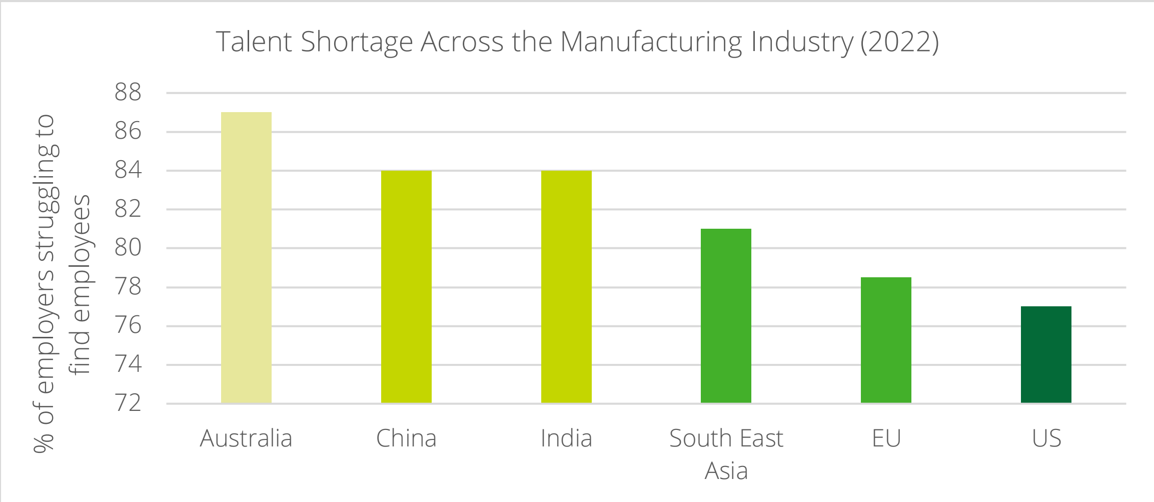
Sources:

- China: The Breakthrough Institute, https://thebreakthrough.org/issues/energy/sins-of-a-solar-empire, viewed 26 Aug 2023.
- Qatar: Equidem "If we complain, we are fired", 2022.
- Saudi Arabia, UK, US, Australia, Thailand: Walk Free, https://www.walkfree.org/global-slavery-index/, viewed 26 Aug 2023.
- India: British Safety Council, https://www.britsafe.in/publications-and-blogs/safety-management-magazine/safety-management-magazine/2022/modern-day-slavery-still-rampant-in-india/, viewed 26 Aug 2023.

Notes:

- Middle East proxied by Qatar and Saudi Arabia.
- SE Asia proxied by Thailand.
- EU proxied by UK.

Labour – Availability of Domestic Skilled Labour

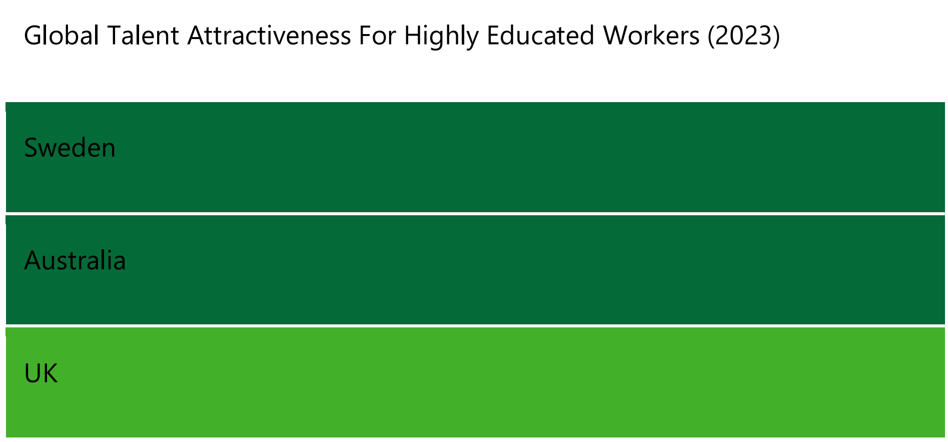


Source: ManpowerGroup, viewed 26 Aug 2023

- Australia: https://go.manpowergroup.com/hubfs/Talent%20Shortage%202022/MPG_2022_TS_Infographic-Australia.pdf
- China: https://go.manpowergroup.com/hubfs/Talent%20Shortage%202022/MPG_2022_TS_Infographic-China.pdf
- India: https://go.manpowergroup.com/hubfs/Talent%20Shortage%202022/MPG_2022_TS_Infographic-India.pdf
- US: https://go.manpowergroup.com/hubfs/Talent%20Shortage%202022/MPG_2022_TS_Infographic-US.pdf
- Singapore: https://go.manpowergroup.com/hubfs/Talent%20Shortage%202022/MPG_2022_TS_Infographic-Singapore.pdf
- EU: UK – https://go.manpowergroup.com/hubfs/Talent%20Shortage%202022/MPG_2022_TS_Infographic-UK.pdf, Germany – https://go.manpowergroup.com/hubfs/Talent%20Shortage%202022/MPG_2022_TS_Infographic-Germany.pdf, Spain – https://go.manpowergroup.com/hubfs/Talent%20Shortage%202022/MPG_2022_TS_Infographic-Spain.pdf, Sweden - https://go.manpowergroup.com/hubfs/Talent%20Shortage%202022/MPG_2022_TS_Infographic-Sweden.pdf.

Notes: Metric assessed by % of employers in the respective country's manufacturing industry reporting difficulties to find workers. Singapore is used as a proxy for Southeast Asia. The EU is proxied by taking the average of Germany, Spain, Sweden and the UK. No data for the Middle East.

Labour – Foreign Skilled Labour



US
Germany
Spain

Source: OECD, https://www.oecd.org/migration/talent-attractiveness/, viewed 6 Sep 2023.

Notes: Calculated by the OECD using a composite indicator that considers quality of labour market, income and tax, access to citizenship, family benefits, R&D, diversity, gender equality, and quality of life.

- EU proxied by Sweden, UK, Germany, Spain.
- No information included for India, Middle East, China or Southeast Asia.

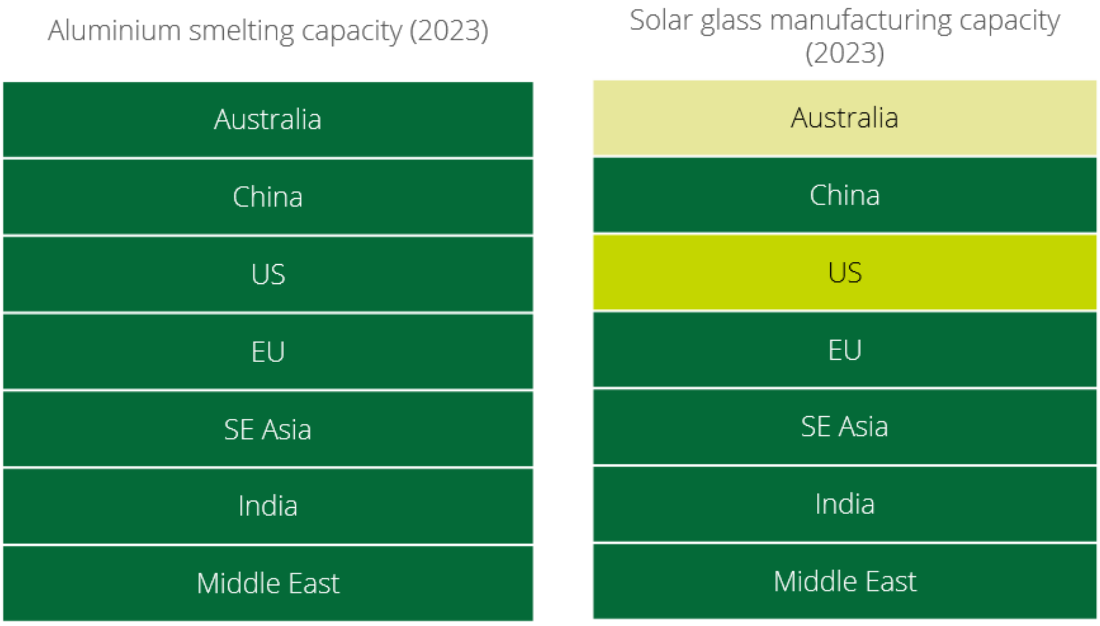
Materials – High Quality Quartz and Metallurgical Grade Silicon Production

Availability of quartz (2023)	Presence of mg-Si production (2023)
Australia	Australia
China	China
US	US
EU	EU
SE Asia	SE Asia
India	India
Middle East	Middle East

Source: US Geological Survey, “Mineral Commodity Summaries 2023”, 31 January 2023.

Notes: A metallurgical silicon plant has been announced for the UAE (The National News, https://www.thenationalnews.com/business/economy/2022/06/24/uaes-ega-to-develop-silicon-metal-manufacturing-unit/, viewed 15 Sep 2023).

Materials – Domestic Glass/Aluminium Industries



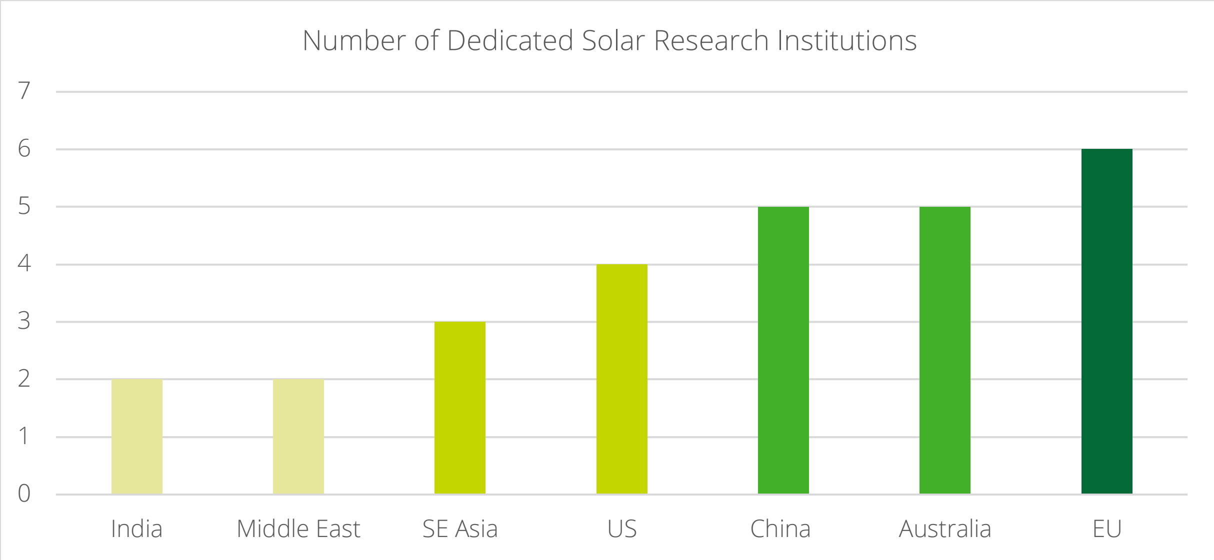
Sources:

- Aluminium: US Geological Survey, "Mineral Commodity Summaries 2023", 31 January 2023.
- Glass: Mordor Intelligence, "Solar photovoltaic glass market size & share analysis", 2023.

Notes:

- Solar glass manufacturing in the US seems likely in the near future as investment has been committed to refurbish glass facilities specifically to manufacture solar glass (Solar Power World, https://www.solarpowerworldonline.com/2023/04/former-automotive-glass-plant-to-be-refurbished-to-make-glass-for-first-solar-panels/, viewed 15 Sep 2023). In North America, solar glass is currently manufactured in Canada (PV Magazine, https://www.pv-magazine.com/2023/05/16/us-solar-glass-provider-to-expand-production-by-6-gw/, viewed 15 Sep 2023).
- ClearVue is a WA-based solar glass company, however, their products are produced offshore.

IP – Strong Solar R&D Capability



Notes:

- India: Jadavpur University Chandradeep Solar Research Institute; Pandit Dindayal Petroleum University School of Solar Energy.
- Middle East: Khalifa University Solar and Device Characterisation Lab; King Abdullah University of Science and Technology Solar Centre.
- SE Asia: Universitas Kebangsaan Malaysia Solar Energy Research Institute; Chiang Mai University Solar Cell Research Laboratory; Solar Energy Research Institute of Singapore.
- US: CSU Centre for Revolutionary Solar Photoconversion; NREL; Sandia National Laboratories; Arizona Research Institute for Solar Energy.
- China: SJTU Engineering Research Centre of Solar Power and Refrigeration; North China Electric Power University; Guangzhou Institute of Energy Conversion; China Electric Power Research Institute; Wuhan New Energy Research Institute.
- Australia: UNSW School of Photovoltaics and Renewable Energy; University of Sydney Solar Research Group; ANU Solar PV Research Cluster; Australian Centre for Advanced PV; RMIT Solar Energy Application Group.
- EU: Aachen University Institute of Solar Research; Fraunhofer Institute for Solar Research; Dalarna University's European Solar Research School; Wageningen University Solar Research Programme; Ege University Solar Energy Institute; Institut National de l'Energie Solaire.

IP – Access to Chinese State-Of-The-Art IP and Technology

Qualitative assessment of trade relationships with China

AU	China is Australia's largest two-way trading partner, accounting for 32.2% of all of Australia's international exports. A bilateral FTA was signed between the two countries in 2015. China is the 6th largest foreign direct investor in Australia. However, Australia has made anti-dumping claims against some Chinese goods.
SE ASIA	China is ASEAN's largest trading partner, accounting for 18% of ASEAN's goods trade. Since 2005, the ASEAN-China Trade in Goods Agreement has caused the value of traded goods to quadruple. In 2020, ASEAN was also China's top trading partner.
MIDDLE EAST	China is the largest bilateral trade partner of the Gulf Cooperation Council, with the UAE being China's second largest trading partner. In 2022, 23% of total investment from China's Belt and Road Initiative went to countries in the Middle East and North Africa. The creation of FTAs with GCC members is high on Chinese foreign policy agenda.
INDIA	China is India's largest goods trading partner, with an average yearly trade growth of over 12% from 2015-2022. However, bilateral investment between the two countries is declining by more than 40% year-on-year. There are a number of economic dialogues established between India and China to further macroeconomic cooperation.
EU	The EU and China are two of the three largest global trading partners, with over 850bn USD in annual bilateral trade in goods in 2022. A negotiation on a China-EU Comprehensive Agreement on Investment has been agreed upon by both parties, but not yet ratified. This would give the EU greater access to Chinese markets. However, the EU has implemented anti-dumping measures on some Chinese goods.
US	China is the US's largest two-way trading partner, with over 500bn USD in trade. However, there is not an FTA between the US and China. Chinese acquisitions have been blocked by the US in the past, and high tariffs on Chinese goods and export controls have been put in place in recent years. The US has implemented anti-dumping measures on some Chinese goods.

Sources:

- Australia: Department of Foreign Affairs and Trade, https://www.dfat.gov.au/geo/china/china-country-brief, viewed 14 Aug 2023.

- US: Council on Foreign Relations, https://www.cfr.org/backgrounder/contentious-us-china-trade-relationship, viewed 14 Aug 2023.
- EU: European Commission, https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/china_en, viewed 14 Aug 2023.
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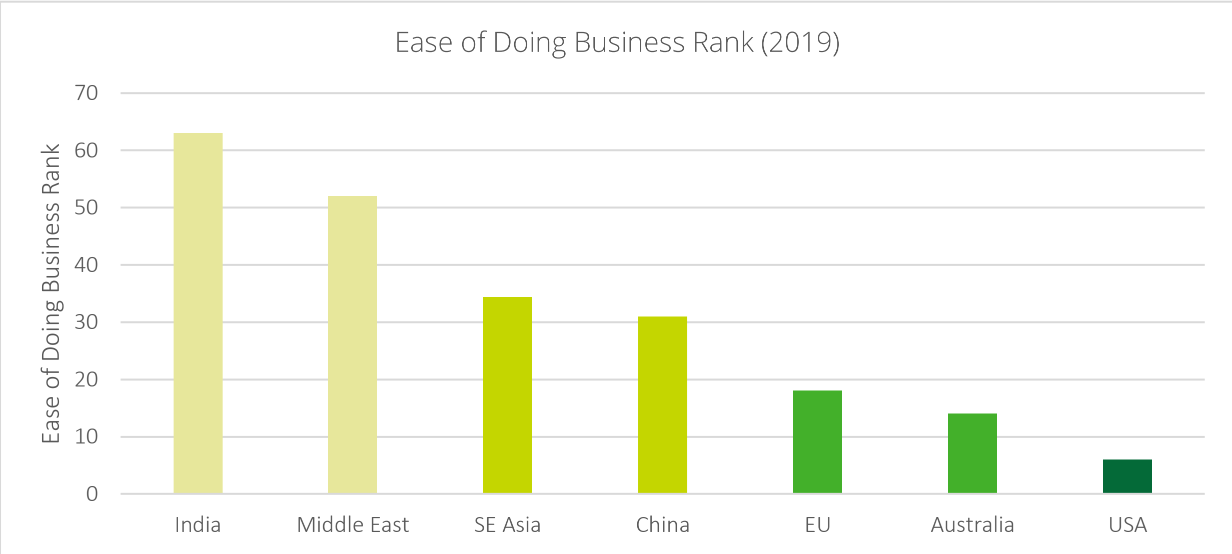
- SE Asia: ASEAN, https://asean.org/our-communities/economic-community/integration-with-global-economy/asean-china-economic-relation/, viewed 14 Aug 2023.
- Middle East: Georgetown Journal of International Affairs, https://gjia.georgetown.edu/2023/06/02/chinas-increasing-role-in-the-middle-east-implications-for-regional-and-international-dynamics/, viewed 14 August 2023.

General – International Investment Certainty



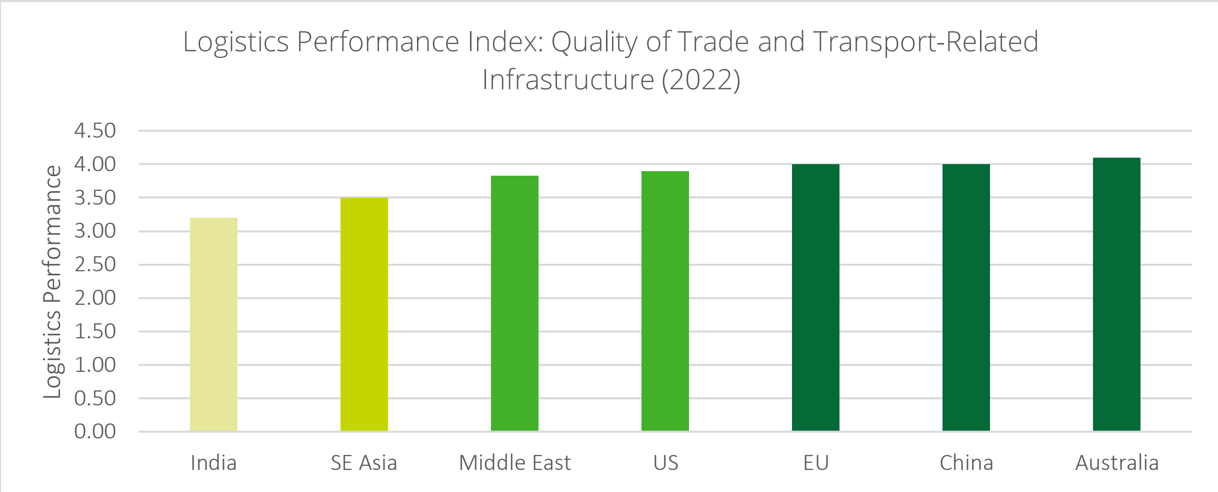
Sources: World Bank, https://data.worldbank.org/indicator/IC.BUS.EASE.XQ, viewed 6 Sep 2023.

Notes:

- EU is proxied by averaging the UK, Spain, Germany and Sweden.
- SE Asia is proxied by averaging Vietnam, Thailand and Malaysia.
- Middle East is proxied by averaging Qatar, Saudi Arabia and UAE.

Calculated by the World Bank to consider the regulatory environment regarding the commencement and operation of a local business.

General – Logistics and Export Infrastructure



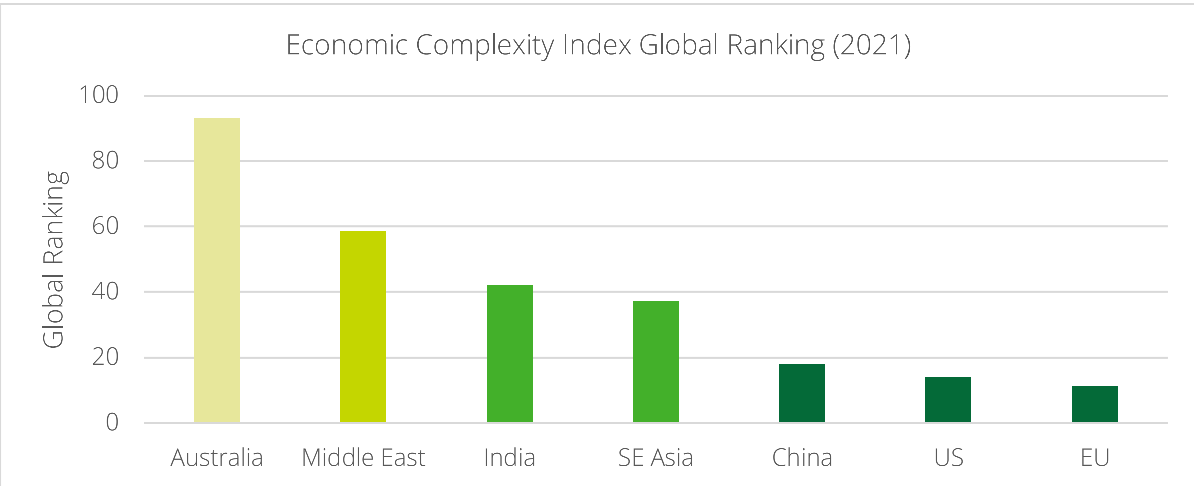
Sources: World Bank, https://data.worldbank.org/indicator/LP.LPI.INFR.XQ, viewed 6 Sep 2023.

Notes:

- EU is proxied by averaging the UK, Spain, Germany and Sweden.
- SE Asia is proxied by averaging Vietnam, Thailand and Malaysia.
- Middle East is proxied by averaging Qatar, Saudi Arabia and UAE.

Each country is given a score between one and five.

General – Manufacturing Expertise



Source: Harvard Kennedy School Growth Lab, https://atlas.cid.harvard.edu/rankings, viewed 6 Sep 2023.

Notes:

- EU is proxied by averaging the UK, Spain, Germany and Sweden.
- SE Asia is proxied by averaging Vietnam, Thailand and Malaysia.
- Middle East is proxied by averaging Qatar, Saudi Arabia and UAE.

This is a relative ranking of the Economic Complexity of each country in relation to each other.

General – Existing Solar PV Manufacturing Policy Support

China	Exact historical and current subsidisation in China is unknown, however, based on stakeholder engagement it is considered to be very high. • Capital subsidies: Significant upfront capital support including concessional land and buildings, concessional loans. • Utility subsidies: lower electricity prices for poly-Si and ingot production, water subsidies.
United States	Inflation Reduction Act (IRA): production and investment tax credits, production credit add-on when local content requirement is met (available to developers, not manufacturers). State-level investment incentives. Section 201 Import tariffs. Uyghur Forced Labor Prevention Act (UFLPA): ban on imports of forced labour goods.

European Union	• Capital subsidies and grants.
	• Important Projects of Common European Interest (IPCLEI) (~10bn USD p.a.): state aid
	• Standards, reporting regulation and Carbon Border Adjustment Mechanism (CBAM): mechanism that helps to reduce the risk of carbon leakage by taxing carbon on imported products.
	• Green Deal Industrial Plan and Net-zero Industry Act: Union's overall strategic net-zero technologies manufacturing capacity approaches or reaches at least 40% of annual deployment needs by 2030 through:
	  ◦ Public procurement and auctions (implementing sustainability, circularity and resilience criteria).
	  ◦ Approvals: simpler and faster permitting procedures for strategic projects
	  ◦ Work permits to facilitate access of third country nationals to EU labour markets in priority sectors.
	  ◦ Net-zero Academies: training for up-skilling and re-skilling of workers in net-zero technologies.
	  ◦ Clean tech/net-zero industrial partnerships.

India	• Production-linked Incentive Scheme (PLI): grants for solar manufacturing related to production.

	• Import tariffs: Make-in India safeguard duty (14.5% on modules and cells imported from China, Malaysia, Taiwan), basic customs duty (25% on cells, 40% on modules) • Local content requirements in auctions and tenders
Turkey	• YEKA-1 integrated manufacturing plant: Low-cost loans, grants, energy support, tax incentives, export support • Antidumping fee: on Chinese modules (25USD/m^2) • Local-content premium: attached to feed-in tariff
Canada	• Investment tax credit • Reduced income tax for zero-emissions technology manufacturing: 7.5% instead of 15%
Middle East	• Stakeholders have indicated Middle Eastern countries that are diversifying from their fossil-fuel based economies are willing to provide significant support for solar PV manufacturing
Australia	• National Reconstruction Fund • AU-US Clean Energy Compact

Sources:

- Deloitte research and stakeholder engagement (see case studies throughout section 5)
- IEA, "Solar PV Global Supply Chains", August 2022.

Notes:

- Table highlights the main policies/financial support related to solar PV manufacturing adopted by the country/region.
- Assessment based on stakeholder interviews and industry players' view on attractiveness of the country/region.

Appendix G: Location Considerations

For the establishment of solar value chain manufacturing capability in Australia, there are several location considerations that are relevant to all or several steps of the value chain. A summary of location considerations across each step is provided in Table 24, each consideration is explored further below.

Table 24: Importance of consideration in the location selection of the solar PV supply chain segment

	POLY-SI	INGOT/WAFER	CELL	MODULE
Proximity to upstream supply chain players	Medium	Medium	Low	High
Proximity to downstream supply chain players	Low	Low	Low	High
Access to a skilled workforce	High	Medium	High	Low
Availability of low-cost renewable electricity	High	Medium	Low	Low
Existing supportive policy/programs	High	High	High	High
Proximity and access to supporting infrastructure	High	High	High	High
Existing industrial hubs	Medium	Medium	Medium	Medium

Proximity to existing import and export infrastructure, centres of demand, and other supply chain players: Given relatively high domestic transport costs within Australia, proximity of production facilities to existing export infrastructure and/or centres of demand will be critical to minimise domestic transportation costs (which have not explicitly been included in the cost assessment completed). Moreover, proximity can shorten lead times, minimize supply chain disruptions, and allow for optimised supply/demand management. In addition, co-location of facilities with upstream and downstream steps of the PV supply chain (see Figure 7-5), and key material providers could present cost benefits for development of an end-to-end domestic manufacturing capability:

- For example, the solar glass and aluminium frame are the main drivers of a module's transport costs due to their weight. Locating near aluminium suppliers will therefore have a positive impact to module manufacturers.
- Locating near existing quartz deposits or existing/planned mg-Silicon smelting (WA, QLD), or an HCl plant, would be beneficial for a poly-Si plant.
- For export-oriented supply chain segments - in Australia this would likely be the case for poly-Si and ingots/wafers – locating adjacent to existing port infrastructure would remain critical (see Figure 7-5), regardless of the development of domestic manufacturing capability across the full value chain. Connection to existing road, rail and port infrastructure capable of supporting large-scale bulk commodity transportation is therefore essential.

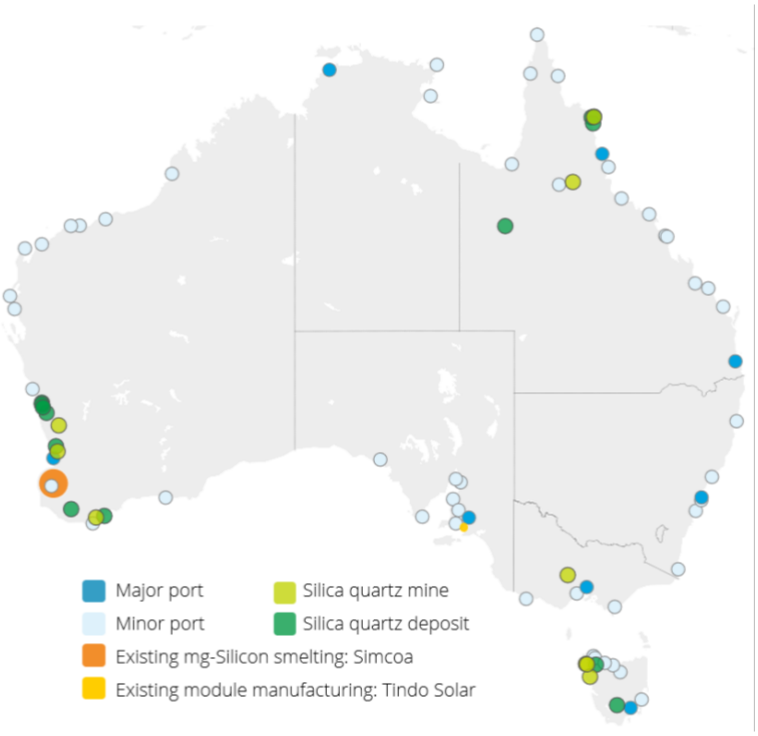


Figure 7-5: Silicon deposits, current solar PV supply chain players in Australia and port infrastructure

Proximity and access to existing utilities: For all segments in the supply chain, it is essential that the necessary enabling infrastructure and utilities are available or able to be connected (i.e., power, natural gas and water). For poly-Si in particular, due to its large baseload power requirement, upgrades to grid infrastructure can present significant cost barriers, therefore sites with existing high voltage (HV) infrastructure with sufficient capacity present a large competitive advantage (e.g., retired or retiring coal plants) (see Figure 7-6). In addition, poly-Si production requires access to sufficient cooling water, e.g., through proximity to a river or lake or desalinated supply.

Availability of low-cost, renewable electricity supply: For Australia to have a competitive advantage in solar PV manufacturing in the long term and have access to international markets with carbon taxes in place, manufactured panels will need to have a low carbon footprint. As highlighted in the sustainability considerations sections above, an important factor to achieve this is using renewable electricity throughout the whole production process. This can be achieved either through decarbonised grid supply, firmed power purchase agreements (PPAs), or co-location with behind-the meter (BTM) assets. For the more energy intensive steps of the value chain (poly-Si and, to a lesser extend ingots/wafers and cells), proximity to high quality solar and wind resources will therefore be critical, to reduce both the requirement for new transmission infrastructure and network charges (which can add ~30% cost on wholesale electricity prices). Figure 7-6 gives an overview of the grid greenhouse gas emissions intensity by State, showing that the grid emissions intensity is lowest in Tasmania and South Australia, and highest in Victoria and Queensland.

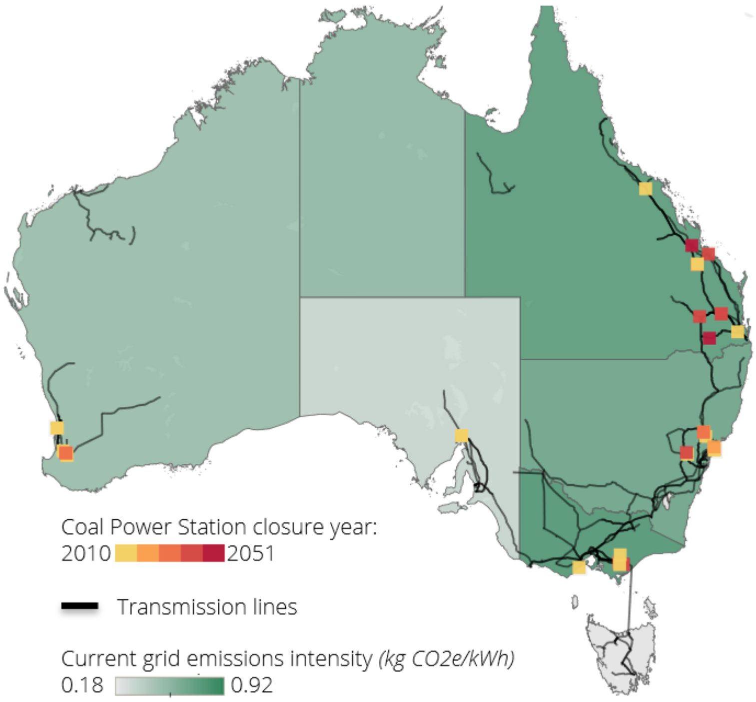


Figure 7-6: Current electricity landscape in Australia
(closing coal power stations, existing transmission lines and grid emissions intensity)

Access to a skilled workforce: Due to the specialized nature of all segments of the solar manufacturing value chain, access to appropriately skilled labour will be essential for successful establishment of a solar component manufacturing facility. The size and capabilities of the workforce (engineers, technicians, workers with manufacturing expertise, etc.) in various regions of Australia are therefore important for location selection. Regions affected by the green energy transition, such as NSW Hunter Valley, Victoria's Latrobe Valley, Central Queensland, and Collie in Western Australia, may present themselves as interesting locations to leverage the existing workforce that will be looking towards reskilling in new industries. More specifically, the following coal mines and plants have their closures planned by 2028: Liddell and Eraring (NSW), Yallourn (VIC), Callide B (QLD) and Muja (WA). Australia already has a shortage of skills in the clean energy industry, and solar manufacturing will compete for talent with other industries. Due to the likely competition for workers, regions that have attractive existing infrastructure, housing and social services may be more inviting and attractive to a prospective workforce.

Existing supportive policy/programs: Due to the barriers identified in each of the value chain steps above, and across the value chain, it will be vital for the government to provide the required support to overcome these barriers and provide an attractive investment environment for new industry. This is discussed further in Section below. Information on existing support in Australia at the Federal and State/Territory level, and its relevance to solar PV manufacturing is provided in Appendix Appendix H:. Due to the role of State governments in many of the enabling areas (including provision of development approvals, workforce support), the presence of effective state support is likely to drive the location decision for manufacturers.

Existing industrial hubs: All of the above outlined location factors are considered most likely to be met in existing industrial hubs. This includes access to existing road, rail, port and utility infrastructure, proximity to adjacent supply chain players, and potential additional State government support through a more coordinated approach to e.g., development and environmental approvals. Additional spill over benefits include access to skilled labour, as industrial hubs tend to attract and retain a skilled and specialised workforce, and unlock cost reductions through shared resources, infrastructure, and services. Additionally, existing industrial hubs may have pre-existing environmental approvals for large-scale manufacturing facilities and are known for fostering innovation and attracting foreign investment. There is also more likely to be community support and social licence in a new plant at an existing manufacturing hub rather than a greenfield site.

Appendix H: Existing Supporting Policy in Australia (non-exhaustive)

Relevance to S2S: high – medium – low – **TBA** - currently closed (may reopen in the future)

Entity	Financial	Worker Reskilling	Streamlined Approvals & Permits	Advanced Manufacturing
Federal	Critical Minerals Strategy (grants, concessional loans): support to help enable early and mid-stage mineral projects overcome barriers to production. High-purity silicon is considered a critical mineral however, it is unclear with poly-Si would be eligible for support. National Reconstruction Fund (equity, concessional loans, guarantees): support targeted at diversifying Australia's industry and economy. $3bn has been committed to renewables and low emissions technologies. $1bn each for value-adding in resources, critical technologies, and advanced manufacturing. Clean Energy Finance Corporation (equity, concessional loans): support for clean energy technologies that have passed beyond the research and development stage and are ready for commercialisation. Northern Australia Infrastructure Facility (equity, concessional loans): Finance or equity arrangements for projects and businesses across sectors such as energy and manufacturing. Available for whole of NT and north QLD and WA. Industry Growth Program (grants) Powering the regions	New Energy Skill Program (financial support for apprenticeships and wage subsidies for workers in clean energy).	Major Project Status (support to accelerate approval process). EPBC Act Reform (faster and more efficient federal environmental approval processes for strategically significant critical minerals projects).	Inquiry into Developing Advanced Manufacturing in Australia: Inquiry considering opportunities for advanced manufacturing in Australia, alongside incentives or reforms to support the sector.

ACT	Renewable Energy Innovation Fund (grants): $12m fund designed to attract investment in the clean energy sector in the ACT. The Fund supports grant funding, trades training innovation, and research partnership. Funding available for renewable energy research, development, and innovation projects.	Skills to Succeed (training support): 4 priorities aiming to develop skills and strengthen skills within ACT's workforce, particularly within the energy industry.	No notable industry development measures.	No notable policy direction.
NSW	Renewable Manufacturing Fund (grants): $250m fund providing grants between 2023-2027 for manufacturing plant, equipment and processes needed to produce renewable energy using commercialised technology. High Emissions Industry Shift (grants): $305m in grant funding to help the manufacturing and mining sectors to reduce emissions.	No notable industry development measures.	State Significant Development (streamlined approval): Certain projects can have an alternate approval pathway whereby their assessment occurs at the State, rather than local Council, level.	Statement on Advanced Manufacturing: 2018 statement supportive of advanced manufacturing, and highlights NSW's vision to be a place for advanced manufacturers to grow (however, clean energy manufacturing not called out as a priority sector).
NT	Advanced Manufacturing Ecosystem Fund (grants): Matched funding between $25k - $500k for manufacturing SME to assist manufacturing projects in NT.	Industry Buildskills Program (training support): Funding to upskill or reskill existing workers affected by industry restructuring, regulatory changes, licensing requirements, or job shortages.	Major Project Status (streamlined approval): Major project status can be awarded to projects which are significant, complex and having strategic impact. Major project status allows for efficient and consistent government processes.	No notable policy direction.
QLD	Made in Queensland (grants): $101.5m fund with grants between $50k - $2.5m (as 1:1 matched funding) to help SME manufacturers adopt new	Manufacturing Skills Queensland (training support): $16.5m NFP industry body supporting	Prescribed Projects (streamlined approval): Allows project to be declared at prescribed project, which	Roadmap on Advanced Manufacturing: 2022 statement supportive of advanced manufacturing,

	technologies and generate-high skilled jobs for the future. Manufacturing Hubs Grant Program (grants): $28.5m Program with grants between $10k - $500k for manufacturing SMEs in specified areas to build advanced manufacturing capabilities. Grants available for technology adoption, skills and training. Industry Partnership Program (grants): $350m investment over 4 years to grow and create jobs across priority sectors like renewable energy manufacturing. Renewable Energy and Hydrogen Jobs Fund (grants): $4.5bn fund to allow energy Government owned corporations to increase ownership of commercial renewable energy projects, including in partnership with private sector.	employers, workers, apprentices and trainees in the manufacturing industry. MSQ will identify key skills needed in the manufacturing sector and deliver training programs.	enlivens Coordinator-General's power to ensure timely decision-making in relating to planning laws and decisions.	and highlights QLD's vision to be a place for advanced manufacturers to grow (with renewable energy technologies and solar components being a priority sector).
SA	Research and Innovation Fund (grants): Seed grant between $50k - $100k (matched funding on 2:1 government:applicant basis) or start grant between $100k - $500k (matched funding on 1:1 basis) for start-ups.	South Australia Skills Plan (under development) will address the workforce requirements to ensure the growth of the energy, mining, resources and clean energy sectors in South Australia. It will redefine priorities for the state and suggest industry driven solutions, place-based funding models and regional access to training, industry and skills labs.	**No notable industry development measures** (however, if passed, the Hydrogen and Renewable Energy Bill 2023 (SA) may work to streamline regulatory processes for renewable energy projects).	No notable policy direction.
TAS	Advanced Manufacturing Accelerating Growth (grants): Matching grant up to $100k provided to	Advanced Manufacturing Skills 2 Manufacturing	Project of State Significance / Major Projects Assessment	Action Plan on Advanced Manufacturing: 2020

	allow advanced manufacturing enterprises to purchase capital equipment.	Program (training support): Co-contribution up to $15k for advanced manufacturers to develop their workforce through non-accredited training.	Process (streamlined approval): Major project status can be awarded to projects which are significant, complex and having strategic impact. Major project status allows for efficient and consistent government processes.	statement supportive of advanced manufacturing, and highlights Tasmania's vision to be a place for advanced manufacturers to grow (with renewable energy being specifically called out).
VIC	Breakthrough Victoria (equity): $2bn government funded investment fund providing venture capital investment to start-ups (whether infant or mature), with advanced manufacturing and clean economy being priority sectors. Industry R&D Infrastructure Fund (grants): Matched funding between $250k-$2m to invest in new or enhanced R&D infrastructure to support Victoria's R&D capability in key industry sectors.	Victorian Skills Plan (training support): collaboration with stakeholders to provide skills-led solutions, drive reform and work together to improve the skills and employment outcomes.	Fast-Track Approval (streamlined approval): If granted approval, projects can be exempted from planning scheme requirements by the Minister for Planning.	Statement on Advanced Manufacturing: 2022 statement supportive of advanced manufacturing, and highlights Victoria's vision to be a place for advanced manufacturers to grow (with zero and low emissions technologies being a priority sector).
WA	Collie Futures Industry Development Fund (grants): Matched funding (1:1) of up to $2m for businesses to develop and expand industries and create jobs in the Collie region.	Collie Jobs & skills centre (training support): one-stop shop centre for Collie local workers affected by the energy transition. The centre provides free training, career and employment advice to individuals and businesses.	Fast-Track Approval (streamlined approval): $22.5m commitment to streamline approvals for green energy proposals. New cross-government Green Energy Assessment Unit to be established, designed to develop clear assessment pathways and provide high-quality, fit-for-purpose, timely support for proponents and investors.	Demand Assessment Report: Government report estimating an additional 50 GW of renewable electricity and storage infrastructure required by 2045. May incentivise future policies which support domestic PV module production.

Abbreviations and Definitions

ACAP	Australian Centre for Advanced Photovoltaics
ACT	Australian Capital Territory
AEC	Australian Energy Council
AEMO	Australian Energy Market Operator
ALD	Atomic Layer Deposition
ANU	Australian National University
APVI	Australian Photovoltaic Institute
AREH	Asian Renewable Energy Hub
ARENA	Australian Renewable Energy Agency
ASEAN	Association of Southeast Asian Nations
AU	Australia
AUD	Australian Dollar
BCA	Border Carbon Adjustments
BNEF	BloombergNEF
BOM	Bill of Materials
BTM	Behind The Meter
c	US Cent
°C	Celsius
CAPEX	Capital Expenditures
CBAM	Carbon Border Adjustment Mechanism
CEFC	Clean Energy Finance Corporation
CER	Clean Energy Regulator
CfD	Contract for Difference
CN	China
CO_2e	Carbon Dioxide Equivalent
CPIA	Chinese Photovoltaic Industry Association
CRI	Commercial Readiness Index
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVD	Chemical Vapour Deposition
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DI	Deionized
DOE	Department of Energy
EL	Electroluminescence
EPBC	Environment Protection and Biodiversity Conservation
ESG	Environmental, Social and Corporate Governance
EU	Europe
EU ETS	EU Emissions Trading Scheme

EUR	Euro
EVA	Ethylene Vinyl Acetate
FBR	Fluidized Bed Reactor
FID	Final Investment Decision
FIRB	Foreign Investment Review Board
FIT	Feed-in Tariffs
FTE	Full-time Equivalent
FY	Fiscal Year
g	Grams
GW	Gigawatt
HPC	Hydrogen Production Credit
HV	High Voltage
IEA	International Energy Agency
IN	India
IP	Intellectual Property
IPA	Isopropyl Alcohol
IPCLEI	Important Projects of Common European Interest
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
IRS	Internal Revenue Service
ISP	Integrated System Plan
ITRPV	International Technology Roadmap for Photovoltaic
IV	Current - Voltage
JV	Joint Venture
kg	Kilogram
kt	Kilotonne
LCOP	Levelised Cost of Production
LGC	Large-Scale Generation Certificate
LNG	Liquefied Natural Gas
LPCVD	Low Pressure Chemical Vapour Deposition
LRET	Large-scale Renewable Energy Target
LTESA	Long-Term Energy Service Agreements
m^2	Square Meter
mg-Si	Metallurgical Silicon, Silicon Metal
ME	Middle East
MPFA	Major Projects Facilitation Agency
MW	Megawatt
NEM	National Electricity Market
NEO	New Energy Outlook
NGER	National Greenhouse and Energy Reporting Scheme

NREL	National Renewable Energy Laboratory
NRF	National Reconstruction Fund
NSW	New South Wales
OECD	Organisation for Economic Co-operation and Development
OPEX	Operational Expenditure
PECVD	Plasma Enhanced Chemical Vapour Deposition
PERC	Passivated Emitter and Rear Cell
PJ	Petajoule
PLI	Production-Linked Incentive Scheme
Poly-Si	Polysilicon
PPA	Power Purchase Agreement
PV	Photovoltaic
QLD	Queensland
R&D	Research and Development
RE	Renewable Energy
RET	Renewable Energy Target
REZ	Renewable Energy Zone
SA	South Australia
SEA	South East Asia
SEIA	Solar Energy Industries Association
SEZ	Special Economic Zone
SHJ	Silicon Hetero-Junction
SRES	Small-scale Renewable Energy Scheme
STC	Small-Scale Technology Certificates
STC , SiCl4	Silicon Tetrachloride
SWIS	South West Interconnected System
t	Metric Tonne
TAFE	Technical and Further Education
TCS, SiHCl3	Trichlorosilane
TEA	Techno-Economic Analysis
TMA	Tetramethylammonium
TOPCon	Tunnel Oxide Passivated Contact
TW	Terawatt
UAE	United Arab Emirates
UFLPA	Uyghur Forced Labor Prevention Act
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
UNSW	University of New South Wales

US	United States of America
USD	US Dollar
Vic	Victoria
VRET	Victorian Renewable Energy Target Auctions
W	Watt
WA	Western Australia
WACC	Weighted Average Cost of Capital
WEO	World Energy Outlook
WTO	World Trade Organization
YEKA	Renewable Energy Resources Zone (Turkey)
YEKDEM	Renewable Energy Support Scheme (Turkey)

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