

SPECIAL REPORT

Australia's semiconductor manufacturing moonshot

Securing semiconductor talent

Bronte Munro, Alex Capri
and Robert Clark

November 2023

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Foreword

This latest report from ASPI on the pivotal issue of semiconductors focuses on the challenge of finding the necessary skilled workforce and ensuring Australia can secure a talent pipeline to support a sovereign manufacturing capability.

This builds on ASPI's 2022 report, *Australia's semiconductor national moonshot*,¹ which called on Australia to be bold and ambitious in its pursuit of a semiconductor-manufacturing capacity and to establish itself in the global supply chain.

Sovereignty doesn't equal a protectionist policy in which all stages of design, development, build and sustainment must be done in Australia. Rather, Australian sovereignty is best understood as the security and resilience created by having our own capability and also trusted and reliable partners who can supply us. This is consistent with understanding that we aren't simply in an era of great-power competition defined by a struggle between the US and China, but one of strategic competition in which all nations are a part, and in which Australia is obligated to play a role as a regional power with global influence.

Critical technologies are at the centre of that strategic competition, just as they were in the Cold War. The competition is multifaceted, involving the need for nations to stay on top of the accelerating pace of technological change. They must do that by maintaining comparative advantage against rivals in defence and security technology; by shaping the technological standards that will directly affect our open societies and allow us to avoid undue influence from foreign governments; and by protecting ourselves against supply-chain risk, whether it arises from malicious intent or natural disaster.

The question of who has long-term security and sovereignty will be determined by who has tech supremacy, standard-setting control and supply-chain resilience. And, while the US will remain Australia's most important strategic and security ally, it's incumbent on Australia not to be a passenger or to reduce our agency over our future decisions and security. That requires Australia to provide the capabilities of a substantive player, not just with the US but with all our strategic partners, particularly in relation to the stability and security of the Indo-Pacific region.

As pointed out by the authors of this report: 'Every item on the Australian federal government's List of Critical Technologies in the National Interest is dependent on semiconductors.'

Australia needs to have onshore manufacturing capability underpinned by sovereign prototyping facilities, because opting out of semiconductor manufacturing would severely constrain Australia's growth as a technological nation and consign it to second-tier status.

Avoiding that plight and strengthening our own security and that of the globe will require collaboration between the government, industry and civil society. This report goes beyond abstract scenarios and highlights opportunities, including public-private partnerships between US industry and academia, friend-shoring practices within the 'Chip 4' alliance and opportunities within NSW and Queensland to highlight how Australia and our partners can achieve this important strategic objective.

Like ASPI's first semiconductor moonshot report, this too is bold and ambitious in its vision and policy ideas, as think-tank reports should be, and I highly recommend it.

Justin Bassi
Executive Director



Executive summary

Semiconductors are a critical component in all modern technologies, from personal communication devices and medical devices to weapons systems. Crucial to producing semiconductors is the availability of a highly skilled workforce, managing clean-room facilities and highly specialised equipment to execute the hundreds of unique steps needed to manufacture a single wafer, depending on the complexity of the chip.²

ASPI's 2022 report, *Australia's semiconductor national moonshot*,³ laid out the strategic reasons why Australia must embark on a capacity-building initiative to create a homegrown semiconductor manufacturing ecosystem. Every item on the Australian federal government's List of Critical Technologies in the National Interest is dependent on semiconductors.⁴

By committing to growing a semiconductor-manufacturing industry from a mature-process-scale baseline, policymakers would position Australia to manufacture chips relevant to the energy, transport, health, IT and defence sectors. Such an industry would enable Australia to execute long-term critical technology strategies in areas such as quantum computing and artificial intelligence, to mitigate supply-chain risk against disruption from conflict or natural disaster, and provide highly skilled jobs in affordable locations, enriching the Australian economy.

It's important to note that both AUKUS Pillar 2 and the Albanese government's April 2023 publication of the Defence Strategic Review reflect a shift in Australia's strategic thinking on defence and national security, and the important correlation and greater cooperation between industry, education and defence priorities, particularly when it comes to technology. Delivering on that shift will be difficult and often costly, but this report provides a series of recommendations of what that correlation and cooperation could look like.

For Canberra, such an endeavour is of the same magnitude as America's historic 'moonshots' during the 1960s and 1970s. It's a once-in-a-generation challenge that will determine Australia's place in the world, and human capital is central to ensuring success. Opting out of semiconductor manufacturing for the long term would severely constrain Australia's growth as a technological nation and consign it to second-tier status.⁵

This report expands on the recommendations made in the 2022 ASPI report for establishing a semiconductor-manufacturing capability in Australia and focuses on the importance of creating a talent pipeline that can support a scaled industry. Achieving a semiconductor moonshot requires stepping up Australia's very respectable semiconductor device fabrication R&D to industry-compatible prototyping via a dedicated facility, together with attracting (through that capability and by government incentives) a semiconductor manufacturer to locate a mature-process-scale foundry in Australia—which will require support from an upskilled Australian talent pipeline. This is an ambitious move but is an essential step in growing such a capability. The ability to grow and maintain a high-skilled workforce is a foundational challenge for Australia that can be addressed through close examination of trailblazing public-private partnerships (PPPs) that aim to provide talent-pipeline security in the US, Taiwan and Japan. Australian governments, industry and academia can emulate and engage with the examples highlighted through case studies in this report to attract semiconductor industry investment, boost talent-pipeline development and strengthen industry R&D. Australia's states and territories all have varied capacity to offer support to a semiconductor-manufacturing capability.

This report is in multiple parts. First, it provides an overview of the moonshot and the case for establishing a small semiconductor manufacturing industry in Australia, and a staged funding approach that could support such an industry (page 8). New opportunities for funding to support that industry are also highlighted (page 10). This report then explicitly considers the global human-capital challenge and the need for Australia

to develop and secure its semiconductor talent pipeline (page 12). Global trends in the use of PPPs to address talent shortages and attract industry investment are outlined, and case studies that offer insights for Australia are examined (page 15). The case studies include analysis of US–Japan academic friend-shoring, a partnership between Taiwan Semiconductor Manufacturing Company (TSMC) and Arizona State University, another between SkyWater Technology, Purdue University and the Indiana state government and finally an examination of Taiwan's approach to talent-pipeline development.

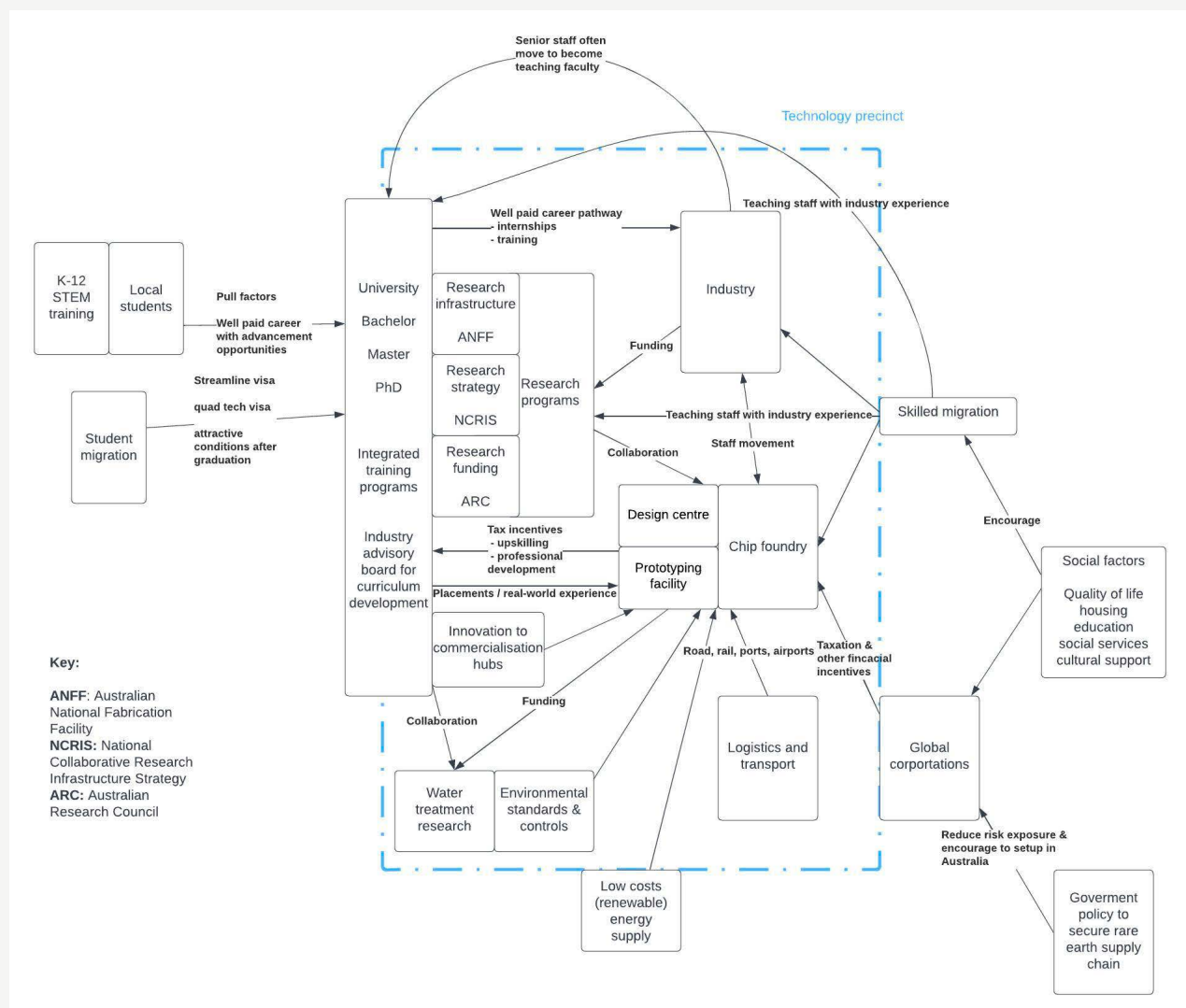
The final part of the report looks at investment opportunities for PPPs in New South Wales and Queensland that can help to establish a semiconductor-manufacturing industry, and secure talent pipelines in Australia. These are examined (page 26) to demonstrate their potential as fertile investment environments for PPPs that will be needed to kickstart the national semiconductor moonshot and address associated talent-pipeline challenges. Nine policy recommendations that address the human-capital challenge and support the national semiconductor moonshot are also made (page 30).

What's the semiconductor-manufacturing moonshot?

Understanding the semiconductor-manufacturing moonshot that we laid out in our 2022 ASPI report is the key to providing the context for this report's complementary recommendations for talent-pipeline development in Australia. The problem that the moonshot, and by extension the argument for talent-pipeline development, is trying to solve is that, if Australia opts out of semiconductor manufacturing, it will severely constrain its growth as a technological nation and its ability to secure its national interests.⁶ To achieve Australia's defence and security priorities outlined in the Defence Strategic Review (DSR) and committed to through technology-sharing agreements such as AUKUS, Australia needs to plan for what sovereign capabilities are required to support those goals in the long term, and semiconductor manufacturing is a necessary foundation to develop.

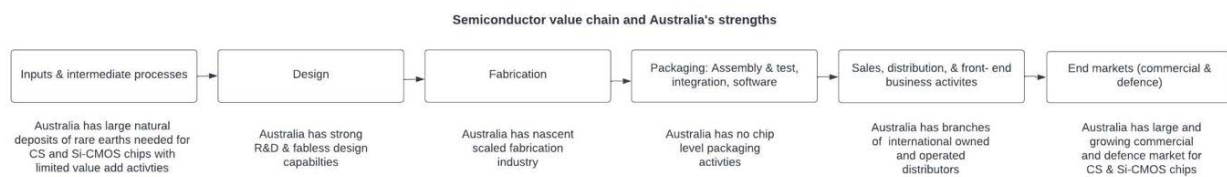
Figure 1 outlines the semiconductor ecosystem and the relationship between an Australian manufacturing capability and talent-pipeline development sources and opportunities, which are the subsequent focus of this report.

Figure 1: Australia semiconductor talent and manufacturing ecosystem



In our previous report, we set out the case for a commercial semiconductor foundry capability in Australia via a public-private partnership (PPP) approach. Central to that approach are 'attractors' of government catalytic funding and incentives, and upscaling the Australian National Fabrication Facility (ANFF) network's semiconductor R&D capability via the establishment of a pilot-production, prototyping facility with industry-compatible fabrication tools. We also outlined the pathway required to attract investment from a global chip manufacturer and we argued that this would build on Australia's foundational strength at the R&D level, in which Australian universities separately would maintain device-level capability in both compound semiconductors (CSs) and silicon complementary metal-oxide semiconductors (Si-CMOS) at mature-process scale. We recommended the establishment of foundry capability in each—in the medium term a CS foundry and in the longer term a Si-CMOS foundry at mature-process scale. Australia's strengths along the semiconductor value chain can be seen through the brief outline in Figure 2.

Figure 2: Australia and the semiconductor value chain



Source: Created by ASPI.

Australia has known reserves of rare earths and other materials used in CS and Si-CMOS chips and a base capability in their design and prototype fabrication.⁷ CS chips are used for a variety of exacting end-use requirements in power electronics, radio communications, sensing and photonic applications,⁸ and are increasingly creating new technological opportunities that underpin nationally identified priorities of Australia's National Reconstruction Fund's (NRF's) List of Critical Technologies in the National Interest.⁹

In our previous report, we estimated that an Australian Government investment and financial incentives of \$1.5 billion would stimulate a total of close to \$5 billion of semiconductor manufacturing activity, including both a CS foundry and a Si-CMOS foundry. This report builds on that recommendation by outlining a *staged* funding approach to delivering semiconductor manufacturing in Australia, in addition to design, packaging and training, as a necessary step to Australia's future security and economic prosperity. The indicative funding breakdown as outlined in the moonshot report¹⁰ is summarised in the box below.

A staged funding approach: creating \$5 billion in semiconductor manufacturing activity via a \$1.5-billion government stimulus

1. \$400 million existing investment that the ANFF represents.
2. An additional \$400 million to upscale the ANFF to commercial pilot-production/prototyping capability with industry-ready tools in a dedicated facility.
3. \$2 billion to establish a CS foundry via a friend-shoring PPP.
4. \$2 billion to establish a mature-process-scale Si-CMOS foundry via a friend-shoring PPP (this is comparable to the US\$1.8 billion foundry being built by SkyWater Technology in partnership with Purdue University—see page 21).
5. \$400 million to establish a sovereign design centre for both advanced CS and Si-CMOS chips.
6. The total of points 1 to 5 of \$5.2 billion is rounded to \$5 billion, as the indicative cost of the two foundries is approximate. Government investment as part of this total, emulating the US CHIPS Act, would be around 30% of the \$5 billion total, or \$1.5 billion.

The key message is that with government stimulus, similar to recent chip policies enacted by allied nations, Australia is eminently capable of taking the step to commercial semiconductor manufacturing. That will involve:

1. building on its world-class R&D base to step up and establish industry-ready national pilot-production, design and packaging centres
2. friend-shoring an established semiconductor firm to site a volume manufacturing foundry in Australia, linked to the pilot capability and a national talent pipeline.



The National Reconstruction Fund as a funding source

The \$1.5 billion required to stimulate a semiconductor-manufacturing capability in Australia reflects a staged, multi-year approach that first establishes ANFF pilot production—as a key step towards a CS and a Si-CMOS foundry—and a co-located sovereign design centre, with the long-term potential for advanced chips (\$800 million in the total \$1.5-billion government investment).

Combined with further government incentives for relevant semiconductor-industry players, this would be a significant attractor for a mature US company to establish a foundry in Australia. The remaining \$700 million of the \$1.5 billion would subsequently be allocated in the form of stimulus packages (17.5% investment) towards each of the two \$2-billion foundries, which would incentivise additional investment. A US company has been identified as an ideal source of investment due to the combination of expertise and leadership in the US industry and the security benefits associated with the US as a close strategic partner of Australia.

The NRF is an obvious funding option. Announced by the federal government in 2022, the fund commits \$15 billion to diversifying and transforming Australia's industry and economy. Semiconductor technologies are integral to achieving the NRF's goals, and semiconductor design and manufacturing are explicitly mentioned under the NRF's 'Advanced manufacturing' category.¹¹

Most recently, an August 2023 Business Council of Australia report proposed several changes to the \$15-billion NRF, including narrowing its investment mandate on fewer priorities to co-invest in five areas of critical sovereign capability that notably include semiconductors, space, additive manufacturing and quantum computing. Some \$8 billion of the NRF has already been allocated, some of it to technology areas underpinned by semiconductors, such as medical manufacturing and critical technologies more broadly. To date, however, the government hasn't made a specific commitment to semiconductor manufacturing. The unallocated \$7 billion in the NRF is a prime resource for policymakers to seriously consider for the stimulus measures proposed in the semiconductor moonshot.

The outlined staged funding approach would initially draw on \$800 million of government investment from the NRF's \$15 billion total. The impact of the \$800 million amount on other NRF priorities could further be softened if it were split between the federal and state governments. Following that initial investment, commercial foundry negotiations involving the proposed government incentive package would follow as stage 2. Critically, this capability will enable the scalability of emerging technology industries that Australia has identified as strategically important, such as quantum and other AUKUS Pillar 2 technologies.¹²

Our analysis (see box) builds on the logic of our prior report's recommendations and the importance of the NRF as a source of catalytic funding by highlighting additional semiconductor manufacturing, design and packaging considerations.

Semiconductor manufacturing, design and packaging: opportunities for Australia

Quantum, advanced chips and pilot production

Semiconductor chips and quantum technologies are often discussed separately. However, while trailing-edge, mature-process-scale chip manufacture is the logical, affordable and supportable entry point for Australia to participate in the global value chain across wide applications underpinning the digital world, near-term access to advanced chips will be central to quantum scale-up. Both outcomes are achievable.

ANFF has R&D capability in both Si-CMOS and CS ‘one-off’ device fabrication. Establishing a separate and dedicated small-throughput, full-wafer pilot production facility fitted with industry-ready equipment, incorporating both deep UV and high-resolution electron-beam lithography tools, would enable both mature-process-scale product innovation and more advanced development at the prototype device level. This would simultaneously be attractive to a closely located mature-process-scale, high-volume commercial foundry and ideally support Australia’s vibrant quantum start-up companies. Both quantum sensors and specific intermediate scale-up needs in quantum computing require high-yield fabrication via industry-compatible processes and tools during the iterative development process, which is costly for a high-volume, low-margin foundry but ideally suited to a pilot-production facility.

Next-generation 3D packaging

There’s additionally an opportunity for Australia to participate in advanced hybrid bonding for a new and competitive era of 3D-based chip products, an advanced chip-stacking package technology particularly relevant to high-performance computing, artificial intelligence (AI) and data centres—and, foreseeably, quantum technologies. With both a pilot-production and foundational semiconductor-manufacturing capability, Australia could well develop such critical know-how in a dedicated facility that could similarly be co-located with the semiconductor design and pilot-production initiatives.

Implementation considerations

ANFF operating model for pilot production: As a supporting capability to both a commercial foundry and quantum / advanced chip national priorities (such as AI), newly established ANFF pilot-production-line operations will need far greater process control and technical management, including facility and personnel security, than currently exists in its researcher-centric model. Government funding of such an ANFF upgrade, as recommended in the 2022 ASPI report, would require that tightening of its operation and its oversight.

Pilot production of Australian start-up technologies will establish credibility and bridge a current gap to foundry entry requirements. This approach is similar to the function of the Interuniversity Microelectronics Centre (IMEC) in Belgium and US Defense Department’s MIT Lincoln Laboratory, which are exemplary commercial and national-security benchmarks, respectively.

Semiconductor design: While various Australian start-up companies have in-house design capability, a *national* capability in both device modelling and circuit design would ideally sit alongside ANFF pilot production. Significant funding for this (\$400 million) was outlined in our 2022 report. It’s envisaged that such a facility would both have a training function and help Australian companies to grow.

Co-location of design and manufacturing capabilities is a feature of the Purdue University and SkyWater Technology partnership, which is highlighted in the 2022 report. That PPP was formed to establish a US\$1.8-billion mature-process-scale Si-CMOS chip research and production facility at Purdue Discovery Park District, alongside a new MediaTek design centre. Taiwan’s MediaTek is the world’s fourth largest design company by revenue.

Semiconductor device forensics: For secure applications involving integrated circuits dependent on offshore sourcing, a device forensics capability will be important. Components of microelectronic devices range from nano- to micro- to macro-scale, and the techniques used to characterise those devices, must also span that entire range.



The global human-capital challenge

Chip talent includes a wide range of STEM-related engineering and professional skills. It includes AI specialists, software engineers, physicists, special-materials scientists, quantum and nanoscience experts, electrical engineers—even architects and structural engineers are needed to build fabrication sites. The problem everywhere is an acute shortage of talent. The US is estimated to need between 70,000 and 90,000 new skilled workers in the next few years just to meet its domestic chip-fabrication goals.¹³ By 2030, the global semiconductor sector will require at least 1 million more skilled workers as demand for chips soars by 80% above 2021 levels.¹⁴

Taiwan, which is the world's chip-manufacturing hotbed, had a monthly hiring gap (a shortage of required talent) of 35,000 in the first quarter of 2022, at least half of which positions were for engineers.¹⁵ Japan needs at least 35,000 new engineers to keep pace with projected investment through 2030.¹⁶ South Korea has projected the need for 30,000 additional engineers in the same time frame.¹⁷

China has the most ambitious semiconductor goals and the largest talent gap. In 2022, it announced funding initiatives worth around \$143 billion, with the aim of becoming self-sufficient in semiconductors by 2035.¹⁸ Such a plan seems grandiose, given China's inability to independently replicate crucial chip-manufacturing technology and materials: Beijing will face a talent gap of 200,000 skilled professionals in 2023.¹⁹

Australia's technology-talent shortage

There's a global scramble for tech talent, and Australia needs to ensure that it implements strategies to secure a portion of global talent that can support the development of an indigenous skills pool. Australia will have to rely mostly on its own resourcefulness to achieve the moonshot.

We currently lack a sufficiently large and specialised pipeline of talent, in both depth and scale, to meet the human-capital requirements of the moonshot, but the realignment of our significant university STEM graduate specialisations and TAFE course credentials to the semiconductor priority area is an achievable and timely starting point.

If Australia is to attract investment from foreign industry players in support of the moonshot, we'll need to ensure that immigration laws support the relocation of skilled workers to support industry activities, which is a strength of the existing Skilled Migration Program.²⁰ Likewise, ensuring that foreign students who want to study in semiconductor-related fields are both able to do so and are provided with visa pathways for working in Australia's domestic industry, as opposed to other global opportunities, will be key.

Currently, Australia has a limited offering of semiconductor education and training pathways: there are only a few examples at some universities.²¹ There's some activity in the vocational sector, such as training in power semiconductors and some provision of training equipment for semiconductor applications. Skilled-workforce development requires new degree programs and facilities at local universities at bachelor's, master's and PhD levels.

The Australian higher education system has been the subject of a wide-ranging government review throughout 2023: the Australian Universities Accord. The accord is a government-funded review of higher education with the aim of achieving long-term security and prosperity for the sector and the nation.²² It's a significant opportunity for the needs of the semiconductor-manufacturing industry to be considered in discussions of priorities for the development of the skilled workforce.

Consideration of the skills needed in coming decades and how best to deliver them have been a key focus throughout the current submission phase of the accord. The submission phase has also highlighted the need to treat the university and vocational sectors holistically. Importance has been placed on education providers coordinating their programs and offering work-integrated learning through micro-credentialled frameworks focused on industry's skills requirements.

The case studies in this report identify the conditions and activities that have enabled the success of PPPs aimed at addressing talent-pipeline security in the global semiconductor industry. Those factors should be encouraged in Australia.

Security considerations in national curriculum development

Solving the human-capital challenge and achieving Australia's semiconductor manufacturing moonshot require, among other things, the development of local talent pipelines by implementing a coordinated semiconductor-related national curriculum. However, policymakers and universities will also need to carefully consider the *security* of leading-edge research on emerging and critical technologies, particularly in the semiconductor and related sectors.

AUKUS, and especially AUKUS Pillar 2 and the Albanese government's April 2023 publication of the DSR, reflect a shift in Australia's strategic thinking on national security and the important correlation between industry, education, defence and national-security priorities. Recognition of the relationship between talent-pipeline development and national security has emerged off the back of the Parliamentary Joint Committee on Intelligence and Security inquiry into the security risks affecting the Australian higher education and research sector. That led to the strategy for countering foreign interference led by the Department of Home Affairs. Under that strategy, the Australian higher education sector²³ and the Defence Department are subject to a new and well-formulated security framework for innovation, science and technology activities with external entities, formally denoted as 'Defence research, innovation and collaboration security'.²⁴

The establishment of the University Foreign Interference Taskforce by the Education Department,²⁵ under the Department of Home Affairs strategy, is indicative of the university sector's recognition of the security challenges associated with talent-pipeline development through education pathways.²⁶

The practical relationship between the university sector and Australia's national-security priorities is also reflected through the recently established Advanced Strategic Capabilities Accelerator (ASCA).²⁷ The ASCA aims to fast-track the scaling up and commercialisation of innovative technology for defence, and that will require significant engagement with curriculums and R&D in Australian universities. While not directly related to chip manufacturing, the ASCA will build a model for strategic engagement that boosts talent-pipeline development and innovation.

Australia's R&D strength

Nationally, despite the currently limited offering of semiconductor education pathways, Australia has a strong R&D capability in semiconductor technologies and related fields. That capability exists in the university sector and CSIRO. It's internationally competitive and well coordinated nationally through the ANFF facilities and network.²⁸ Australia is also a leader in adjacent technologies, especially quantum technology. Quantum computing will require advanced semiconductor manufacturing capabilities to scale up activities, and cutting-edge Australian R&D in that space (outlined in the 2023 National Quantum Strategy)²⁹ is a driver for partnership with semiconductor-manufacturing companies. More generally, Australia's advanced R&D credentials are a powerful source for innovation in the sector and an opportunity for pilot production by foreign semiconductor firms looking at Australia as an option for foundry investment.

The potential of Australia's R&D sector has already begun to be leveraged at the state level by the NSW Government through the establishment of the Semiconductor Sector Services Bureau (S3B). S3B is a serious, exceptionally well-led initiative comprising a consortium of NSW universities and the ANFF, together with industry partners, focused on creating a local talent pool in semiconductor design, initially to enable access to global foundries.³⁰ S3B brings together a community of partners in a joint venture to expand the semiconductor ecosystem, providing market intelligence, supporting talent development and facilitating access to supply chains. It was established following the publication of the *Australian semiconductor sector study* by the NSW Chief Scientist and Engineer and the University of Sydney's Nano Institute in 2020.³¹ The report aimed to identify capabilities, opportunities and challenges associated with increasing NSW participation in the global semiconductor value chain.

S3B has worked to address the training vacuum in the semiconductor industry by using PPPs and to leverage the baseline R&D capability in Australia's university sector. Key initiatives include establishing education pathways in microelectronics through micro-credentialling (short, focused credentials that provide competency in a specific in-demand field or skill) in collaboration with the New Education and Training Model for the Western City Parklands Authority, the University of Sydney and Cadence Design Systems. Efforts have also extended beyond NSW through cooperation with the University of South Australia and engagement with Taiwan in semiconductor training.³²

Most recently, S3B has signed a memorandum of understanding with IMEC in Belgium,³³ which is one of the world's leading R&D labs in nanoelectronics. IMEC, which was established in the 1980s, offers tailored services adapted to customers' needs, from the design of application-specific integrated circuits, including radiation-hardened designs, to package development, testing, qualification and volume production. It's an example of the recommended pilot-production facility that Australia could establish at an appropriate entry point.



PPPs as a solution to the technology-talent shortage

Australia is taking significant first steps to address higher education and research in technological areas of national importance. A next key step is to use the collaborative relationship between the Australian Government and the university sector to encourage the global semiconductor industry to invest in Australia, via PPPs.

PPPs are the most effective model for achieving the mutually dependent goals of developing Australia's semiconductor talent pipeline and committing to the manufacturing moonshot. A holistic approach is required in order to create a skilled workforce, jobs and career pathways and to prevent a brain drain. Industry and academic collaboration creates a positive feedback loop of talent and resource sharing that enables innovation and R&D to occur in a way that ensures scalability, economic growth and commercial leadership in technologies of critical importance to national security.

Learning from global policy trends and PPPs

Liberal democracies such as Taiwan, the US, South Korea and Japan have begun executing bold national plans that capitalise on PPPs to attract domestic investment from the semiconductor industry and to develop and safeguard talent.

There are two broader geostrategic factors driving those global policy trends. First, protecting supply chains from potential disruption, particularly conflict between China and Taiwan, is of strategic concern globally due to Taiwan's production of 60% of the world's semiconductor chips and 90% of the world's advanced chips.³⁴ Second, policies are also aimed at limiting China's access to semiconductor-manufacturing technologies in an attempt to prevent Beijing leading in critical and emerging technologies such as AI and quantum computing.

The right-shoring and ring-fencing of semiconductor ecosystems through PPPs is occurring mainly among the world's major semiconductor-manufacturing nations: Taiwan, the US, South Korea and Japan. Washington has expended considerable diplomatic effort in the pursuit of the so-called 'Chip 4' Alliance, which comprises those four countries.

Sceptics might argue that Chip 4 is an alliance on paper only. That's due to historical tensions between Japan and South Korea and asymmetries in their core competencies in semiconductors. Japan excels in materials and manufacturing equipment, while South Korean companies are known for logic chips and related technologies. For a friend-shored Chip 4 arrangement to succeed, both countries must increase trade and supply-chain integration, which will happen largely because of geopolitical, not economic, drivers and will require a closer alliance.

Geopolitical realities are driving change. In February 2023, trade ministers from Japan and South Korea met virtually to discuss moving forward and overcoming roadblocks.³⁵ In August 2023, in a meeting at Camp David, US President Biden presided over a three-way agreement that included South Korean President Yoon Suk Yeol and Japanese Prime Minister Fumio Kishida.³⁶ The Camp David agreement centred on a joint response to China's growing military and economic assertiveness. The relevance of the national-security / semiconductor nexus was on display, and we should expect to see the Chip 4 alliance grow in importance.

Taiwan has been a leader in establishing PPPs with domestic and foreign industry and academia to extend its chip-manufacturing resilience and to gain access to a wider talent pool. Other new academic-to-academic partnerships aimed at talent-pipeline security are also emerging in India, Eastern Europe and elsewhere. Here, again, national-security issues will necessitate greater cooperation within the Chip 4 Alliance.

There is global breadth in the PPPs emerging from Taiwan and policies that support and protect the skilled workforce (see box). Australia should seek to emulate and engage with Taiwan during this period of supply-chain diversification and investment to secure the expertise required to kickstart the semiconductor-manufacturing moonshot.

Taiwan's PPP activity to secure and develop talent pipelines

In Taiwan, the National Yang Ming Chiao Tung University signed cooperation and student-exchange agreements with four Indian institutes of technology (IITs), including IIT–Bombay (Mumbai), IIT–Delhi, IIT–Kanpur and IIT–Madras.³⁷

National Taiwan University has increased its scholarship programs for visiting students from Eastern European countries and actively recruits prospective engineers and STEM-focused specialists from Lithuania, Poland, the Czech Republic and Slovakia.³⁸

The perception in Taiwan is that many of those students will eventually return to Taiwan with their expertise or will work with Taiwanese companies that are embedding into new global ecosystems.³⁹ Academic friend-shoring is therefore seen as a positive-sum game that increases talent among allies, as opposed to leading to a brain drain resulting from competition among countries to acquire talent.

When it comes to issues of national and economic security, there are exceptions. State-backed attempts by Chinese semiconductor companies to hire or poach Taiwanese engineers and tech talent have met with stiff resistance from Taiwan's government, and, equally, from Taiwan's civil society, for ideological and existential reasons.

In May 2022, Taiwan passed laws that reduce China's access to talent. It amended its National Security Act to list the poaching of talent from leading-edge industries as a form of economic espionage.⁴⁰ That was singularly aimed at China. An official statement from Taiwan's Ministry of Justice stated that the amendments were necessary to 'better protect the competitiveness of our high-tech industries ... and to prevent the trade secrets in key national technologies from being infringed by hostile foreign forces and their proxies'.⁴¹

The US doctrine of restructuring critical sourcing and manufacturing activities, as outlined in the 2022 CHIPS Act,⁴² is also shaping policies aimed at protecting physical supply chains from disruption, developing talent pipelines, cutting out foreign entities (predominantly China) from supply chains and blocking access to technology transfer. Restrictions cover access to academic R&D related to advanced semiconductor manufacturing, intellectual property (IP) transfers and prototype development. Sanctions and export controls have also prohibited collaboration between individuals, companies and governments, forcing a fracturing in the industry and academic relationships between US entities and foreign entities, primarily from China and Russia.

Globally, industry has indicated support for such national policies,⁴³ which provide financial incentives to diversify semiconductor supply chains. Supply-chain diversification through PPPs makes the limited pool of semiconductor manufacturers more resilient to disruption—whether conflict driven or natural—and ensures access to large talent pools and R&D hotbeds that enable long-term viability.

Australia is in a good position to learn from the successes and failures of members of the Chip 4 and other global partners in talent-pipeline security in semiconductor manufacturing. This is also an opportunity to collaborate under the auspices of partnerships such as AUKUS and the Quadrilateral Security Dialogue to generate mutual supply-chain security. Given the importance of the semiconductor-manufacturing moonshot to high-priority defence technologies, notably those listed under AUKUS Pillar 2, Australia should ensure that our allies understand how investment in Australia's semiconductor industry will meet shared strategic goals and create a diversified supply chain with a trusted partner.

The following four case studies are designed to inform and highlight the context, practicalities and opportunities of trailblazing PPPs within the semiconductor industry:

- The first case study examines academic friend-shoring through PPPs between the US and Japan, which are aimed primarily at developing the talent pipeline.
- The second case study examines the partnership between Arizona State University (ASU) and Taiwan Semiconductor Manufacturing Company (TSMC), and the role of the US Government policies in driving industry investment and skilled-workforce development.
- The third case study examines a domestic PPP between US semiconductor manufacturer SkyWater Technology and Purdue University, and the role of the Indiana state government.
- The fourth case study examines domestic PPPs in Taiwan between TSMC and universities to help to secure national talent pools.

The four case studies form a diverse picture of the styles of PPPs that could be adapted to Australia's academic, industry and policy landscape.

Case study 1: US–Japan academic friend-shoring

The US and Japan have created policy that drives the development of semiconductor-related curriculums and builds a workforce that can strengthen both countries' STEM-related pools using PPPs. This has attracted investment from semiconductor industry players, including Micron Technology Inc., IBM and Google.

Drivers of the partnership

Driven by mutual geopolitical and national-security interests, Washington and Tokyo have accelerated public–private linkages between universities and leading-edge technology companies. Like the US, Japan has historically been a semiconductor powerhouse but has offshored chip fabrication in recent decades. Like Washington, Tokyo is keen to re-shore the fabrication portion of global semiconductor value chains, but it recognises the security and strategic benefits of aligning its strategy with the US.

Rapidly growing PPPs between US and Japanese universities, leading businesses and governments aren't confined to just semiconductor ecosystems. Collaborative curriculum development in the STEM areas has become an overarching objective.

Key activities

Micron Technology investment

In May 2023, Micron Technology Inc., an American semiconductor company and the largest foreign investor in Japan over the previous five years, announced the launch of the US–Japan University Partnership for Workforce Advancement and Research and Development in Semiconductors (UPWARDS).⁴⁴

Micron committed US\$60 million, over five years, among a group of 11 UPWARDS participating universities from across the US and Japan to develop curriculums and to secure and develop a high-skilled workforce. In the area of semiconductors, the aim is to enhance the experience of 5,000 students per year by providing both classroom learning and hands-on practice in manufacturing and production environments, such as memory-chip clean rooms.⁴⁵

The UPWARDS universities in the US include Purdue University, Boise State University, Rochester Institute of Technology, Rensselaer Polytechnic Institute, the University of Washington and Virginia Tech. Japanese participants include Hiroshima University, Kyushu University, Nagoya University, Tokyo Institute of Technology and Tohoku University.⁴⁶

Academic friend-shoring for semiconductor talent development with strategic partners in key countries is the new normal in the geopolitical landscape. For example, in May 2023, Purdue University signed a separate agreement with the Indian Government and the India Semiconductor Mission on skilled-workforce

development and joint research and innovation in the fields of semiconductors and microelectronics.⁴⁷ (Below, we feature an in-depth case study of Purdue University and its PPP with SkyWater Technology, the US semiconductor manufacturer, which is investing US\$1.8 billion in an affiliated chip-manufacturing plant.)

One of the defining objectives of the UPWARDS initiative is the participants' commitment to diversity, equality and inclusion, which emphasises drawing in students from traditionally underrepresented portions of the population within the tech sector, namely women and minorities.

Those values, along with underlying geopolitical imperatives, were clearly on display at the signing of the UPWARDS agreement, which was presided over by, among others, US Secretary of State Antony Blinken and Japan's Minister of Education, Culture, Sports and Science and Technology, Keiko Nagaoka.

Overall, Micron announced investments of US\$3.6 billion in Japan, which will include the installations of extreme ultraviolet lithography to make the next generation of dynamic random-access memory, called '1-gamma' chips, at its Hiroshima plant.⁴⁸

IBM investment

US and Japanese government engagement further incentivised industry investment. IBM announced a US\$100 million investment over 10 years in a quantum computing partnership with the University of Tokyo and the University of Chicago. IBM's investment is aimed at developing the world's first quantum-centric supercomputer powered by 100,000 qubits, which is a technology reliant on advanced semiconductors.⁴⁹

Google investment

Google has announced a US\$50 million investment over 10 years in a partnership with the University of Tokyo and the University of Chicago. This academic-industry partnership will focus on the development of a fault-tolerant quantum computer.⁵⁰

Key takeaways for Australia

All these endeavours rely heavily on collaborative curriculum development and a belief in shared values and the risks posed by would-be geopolitical adversaries. This case study demonstrates the actions that allies and partners are taking to secure semiconductor supply chains. There's a clear opportunity for Australia to leverage its position as a trusted and stable partner to attract investment in onshore semiconductor-manufacturing capabilities.

The role of the US and Japanese governments in developing policies that signal and incentivise investment from industry and partnerships with universities on R&D and curriculum development is evident. Australian policymakers need to be able to clearly communicate to industry areas of investment priority, both at the state level and under federally coordinated policy road maps for the semiconductor industry.

Case study 2: Taiwan Semiconductor Manufacturing Company and Arizona State University

TSMC invested in the building of two semiconductor fabrication plants ('fabs') in Phoenix, Arizona,⁵¹ and established a partnership with ASU, which has the largest engineering program in the US and is located in Phoenix.

TSMC's investment has been supported by US Government incentives through the CHIPS Act. TSMC has been engaged with ASU on talent-pipeline development since its initial investment, and that development is a key factor in supporting TSMC's long-term activities in Arizona.⁵²

TSMC's building of the fabrication plants in Phoenix has been hampered by delays and shortages of skilled labour, which shows that talent-pipeline concerns are affecting even the largest industry players globally.⁵³ The construction of clean-room facilities and the handling of advanced machinery require specialised builders.⁵⁴

For Australia, this highlights the need to prioritise domestic talent development early on to ensure that a strong base of skilled workers is available to meet our technology and defence needs. It also highlights why partnerships with foreign industry that has access to the existing talent pool are necessary to support the building of Australia's own manufacturing capability.

Drivers of the partnership

TSMC's decision to invest in Arizona was driven by economic opportunities and incentives, as well as a desire to diversify the location of its manufacturing activities and position itself for long-term leadership in semiconductor technologies by ensuring enough access to talent and R&D.⁵⁵ Similar investment by TSMC in Japan⁵⁶ is indicative of that strategy, and the companies' varied experiences in both investments offer Australia PPP models to learn from.

The US\$52.7 billion in tax incentives and grants allocated under the CHIPS Act to support domestic semiconductor manufacturing in the US was a key driver in TSMC subsequently tripling its initial investment in Arizona from \$12 billion to \$40 billion.⁵⁷ It demonstrates the importance of federal policy in driving economic growth.

State-level initiatives pre-dating the CHIPS Act have also laid the groundwork for growth in Arizona's semiconductor industry. In 2021, the Arizona state government supported the establishment of the New Economic Initiative led by three public universities: ASU, the University of Arizona and North Arizona University.⁵⁸ The initiative involves public-private collaboration across Arizona's three public universities, industry and the state government to boost Arizona's high-tech industry.⁵⁹ US\$150 million has been committed to the initiative for the 2023 fiscal year;⁶⁰ that funding is spearheading efforts to bolster the talent pipelines, R&D capacity and infrastructure required to grow Arizona's semiconductor-manufacturing capability.

From the US Government's perspective, the strategic value of TSMC's investment stems not only from the national-security imperative behind securing talent pipelines and onshoring supply chains, but from the economic value of the investments. The TSMC investment is predicted to create 4,500 high-wage jobs, 21,000 construction jobs and more than 13,000 jobs in supplier companies.⁶¹ The infrastructure development needed to support the industry, such as housing and roads, will also drive significant economic growth.

TSMC and ASU have engaged on talent-pipeline development since TSMC's initial investment in Arizona,⁶² and that development was a contributing factor behind the establishment of operations in Phoenix.⁶³ In July 2023, TSMC and ASU announced a formal partnership agreement aimed at supporting training, recruitment and projects that deepen their relationship.⁶⁴ Through partnership with ASU, TSMC had access to more than 30,000 students enrolled in ASU's Ira A Fulton School of Engineering in 2022.⁶⁵

Key activities

TSMC investment in a fabrication facility

In 2020, TSMC announced an investment of US\$12 billion to build a fabrication facility in Phoenix, which would create demand for 1,900 full-time skilled workers over five years; production is to start in 2024.⁶⁶ TSMC increased its investment to US\$40 billion and committed to building a second advanced manufacturing plant in 2022,⁶⁷ following the Biden administration's CHIPS Act, which committed US\$52.7 billion over five years to bolster national security through technology investment.⁶⁸

ASU curriculum development with industry

Arizona has had a role in US semiconductor manufacturing since Motorola opened its fabrication plant in 1956.⁶⁹ In 2004, ASU bought a Motorola R&D facility, repurposing it into the ASU MacroTechnology Works.⁷⁰ This ASU location is available to community partners and university researchers and facilitates the growth of the semiconductor industry and talent pipeline.

ASU supports the facility and through its microelectronics programs. ASU's engineering school has more than 7,000 students studying in microelectronics-related fields.⁷¹ The curriculum is supported by more than 150 faculty staff who engage in R&D and teach microelectronics. Strategic oversight for microelectronic programs within the university's engineering school is provided by the School of Manufacturing Systems and Networks, which is focused specifically on curriculums that build the semiconductor workforce.⁷²

ASU engages with TSMC and other industry partners, notably Intel, to develop curriculums that meet industry needs.⁷³ Where industry expertise is required, ASU has support from TSMC and Intel experts who assist by teaching coursework and overseeing practical training in advanced microelectronic skills.⁷⁴ Those individuals often take up faculty positions in later stages of their careers, adding to the pool of industry-experienced experts at ASU. This unique and extensive engagement is coordinated through ASU's Microelectronics Industry Council, which works to align private resources with government strategic investment.⁷⁵

As a result of those PPPs, ASU is the largest provider of engineers for Intel⁷⁶ and works closely with TSMC.⁷⁷ ASU students in specific degree programs undertake year-long training programs with TSMC in Taiwan, where they're trained using world-leading advanced manufacturing facilities in anticipation of the opening of TSMC's foundry in Arizona. The key to attracting talent to the ASU microelectronics programs is the unique industry collaboration that provides almost guaranteed employment avenues for students.

Key features of ASU's unique offerings in microelectronics include the following:

- Multiple majors and specialist programs are provided within the microelectronics field in bachelor and graduate degrees and in non-degree stackable credentials available through online learning platforms.⁷⁸
- On-demand, low-cost skills development and non-degree courses for rapid upskilling and reskilling are available. Specific specialisation areas include additive manufacturing processes, battery technologies, industrial automation, materials science for technological applications, rapid prototyping and tooling, rapid prototyping using 3D printing, semiconductor characterisations, semiconductor packaging, and materials science for advanced technological applications.⁷⁹
- Professional programs for engineers and technicians are designed for both managers and engineers. They include 'Lean Six Sigma' certifications, design-of-experiments specialisations and engineering project-management certifications.⁸⁰
- Internship and research opportunities with industry partners are available, which also benefits industry by giving it first access to highly skilled graduates.

Sociocultural considerations

An additional factor key driving TSMC's investment is not only Arizona's and ASU's ability to provide access to a skilled workforce, but also their parallel focus on sociocultural developments⁸¹ that support the specialist workers from Taiwan whom TSMC has sent to Arizona to construct and eventually operate the plants.⁸²

While communication and collaboration challenges between local hires and Taiwanese construction workers brought in to help build the fabrication facilities still occur,⁸³ ASU, TSMC and the Arizona state government have tried to be cognisant of those natural challenges.

The promotion of Mandarin-language programs and Taiwanese cultural celebrations held by ASU are some of the cornerstone efforts to assist in bridging the two different cultures. Colloquially referred to as 'Little Taipei', this cultural development in support of TSMC's investment is attracting additional Taiwanese investment in Arizona.⁸⁴ In 2023, the Arizona Commerce Authority opened a trade and investment office in Taiwan to help manage economic collaboration and opportunities for foreign direct investment.⁸⁵

Key takeaways for Australia

This PPP case study offers insights that Australia can use for guidance on how to incentivise talent in the semiconductor industry. Australia's own industry and talent pools are nascent in comparison to the TSMC-ASU partnership. However, the case study demonstrates how, while industry is the driver of PPPs, governments can facilitate and encourage depth and longevity in critical sectors. The increase in TSMC's

investment following the CHIPS Act highlights how governments have an important role in reducing the barriers to entry for organisations and signalling investment priorities through policy.

TSMC isn't immune to the global challenge of talent shortages in the semiconductor industry. The opening of the new foundry has been pushed back from 2024 to 2025 due to shortages in skilled workers able to construct the highly advanced manufacturing facilities. Water-security concerns in Arizona that could affect TSMC's activities have also been subject to public scrutiny, which the Arizona state government has responded too.⁸⁶

Despite its setbacks, the TSMC case study illustrates strategies to mitigate the other aspects of the talent-shortage challenge. It illustrates the two-way talent pipeline between industry and academia, in which the ASU–TSMC partnership provides retiring skilled employees with a pathway opportunity to transfer their knowledge to the next generation of talent through curriculums. This provides an avenue for growth and scalability for Australian universities looking to expand their semiconductor curriculums to support and attract semiconductor manufacturing. Investment from industry also provides incentives for Australia's strong R&D talent to remain here, rather than looking for opportunities in the semiconductor industry overseas.

Case study 3: SkyWater Technology, Purdue University and the Indiana state government

SkyWater Technology, which is a US-based semiconductor-manufacturing company, and Purdue University in Indiana have partnered to grow semiconductor talent pipelines that directly support industry needs by leveraging Purdue's strong R&D and innovation ecosystem. The partnership was assisted by strong support from the Indiana state government in both a coordination and a fiscal capacity, and more broadly from the US Government under the subsequent CHIPS Act.

Drivers of the partnership

SkyWater's partnership with Purdue is largely driven by access to a pipeline of skilled workers required to support and grow SkyWater's commercial activities and US technology talent and leadership, as well as Purdue's reputation as an R&D innovation hub.⁸⁷ The Indiana Government played a critical role by providing an incentive road map for industry. Its assistance in navigating federal funding opportunities under the CHIPS Act was critical in accelerating the partnership between SkyWater and Purdue.⁸⁸

SkyWater's investment in Purdue was pre-dated by the launch of Purdue's Semiconductor Degree Program in May 2022. The program provides a comprehensive suite of interdisciplinary degrees and credentials in semiconductors and microelectronics, building the university's research excellence.⁸⁹

Purdue's reputation for encouraging the translation of R&D into scalable innovation, reflected by some 13 start-up companies, has been based on its IP⁹⁰ and was also an incentivising factor for SkyWater's investment. SkyWater's manufacturing facility will be based in Purdue Discovery Park, which is an innovation hub that bridges Purdue's activities with industry partners through shared facilities, collaborative R&D and student engagement, resulting in a highly skilled workforce and growth for the industry.⁹¹

Investment from government and SkyWater was also driven by Purdue's reputation as a trusted entity with a strong adherence to IP security in the policies, processes and procedures used to handle sensitive materials and ideas that are developed in tandem with government and industry partners.⁹²

Key activities

SkyWater fabrication facility investment

In July 2022, SkyWater announced plans to invest US\$1.8 billion in a fabrication facility at Purdue University, supported by the Indiana Economic Development Corporation.⁹³ The facility, which includes a state-of-the-art

clean room, will be built in Purdue University's Discovery Park district. Discovery Park is an innovation hub that bridges Purdue's activities with industry partners through shared facilities, collaborative R&D and student engagement, which results in a highly skilled workforce and facilitates business growth for the industry.⁹⁴

Purdue's investment and strategic leadership

In 2023, Purdue committed US\$100 million in funding to semiconductor research and learning facilities through the 'Purdue Computes' initiative. The funding is a part of the university's three-pronged strategy to position itself as a national leader in semiconductor workforce development.⁹⁵

Purdue's strategy is driven by its recently appointed President, Mung Chiang, who has practical industry experience in microelectronics and semiconductor manufacturing.⁹⁶

The strategy involves:

- establishing the Semiconductor Degree Program
- undertaking research supported by the CHIPS Act
- establishing PPPs with industry in the semiconductor supply chain and with global partners.

Those three tactics are designed to support each other. As expressed by the Purdue Board of Trustees, this signals a tangible commitment to being a global leader in areas significant to Purdue students and society more broadly. As a result of the committed funding and facility development, the semiconductor industry partnership with Purdue has grown beyond SkyWater. In June 2022, MediaTek Inc., a leading global chipmaker, announced plans to build a chip design centre in Purdue's Discovery Park.⁹⁷

Purdue Semiconductor Degree Program

Purdue's establishment of PPPs that address talent shortages in the semiconductor industry is underpinned by its Semiconductor Degree Program, which offers a suite of credentials at graduate and undergraduate levels and flexible learning pathways, including virtual labs, internship opportunities and design-to-fab projects. The program is supported by partnerships and engagement with government-funded initiatives, which have helped to shape priority areas for investment and instilled confidence in the industry, which is also used to teach the program and provide guidance in curriculum development, teaching support and experience in manufacturing facilities.

The Semiconductor Degree Program's value is derived from its focus on five unique offerings that distinguish it from other engineering programs:⁹⁸

- 6-in-1 content: Chemicals/materials, tools, design, manufacturing, and packaging are the semiconductor industry's key steps, along with supply-chain management.
- Choice of credentials: Participants can choose from a master of science degree, stackable certificates at the postgraduate level, a bachelor of science minor/concentration and associate degrees through partner Ivy Tech Community College.
- Flexible modality: Both residential and online programs are available. The online offering is the first of its kind in the US.
- Innovative delivery: The program is delivered through the online learning platform nanoHUB and virtual labs, cooperative and internship opportunities, and design-to-fab team projects.
- Broad partnership: Purdue partners with the US Defense Department's SCALE (Scalable Asymmetric Lifecycle Engagement) program, the American Semiconductor Academy and other CHIPS Act workforce consortiums. The program is also advised by a leadership board of senior industry executives.

Purdue engages heavily with industry in the creation of its workforce-development programs. The Semiconductor Degrees Leadership Board comprises corporate leaders who directly contribute to curriculum development and implementation.⁹⁹

Key takeaways for Australia

The SkyWater–Purdue partnership is significant, as it's directly comparable with Australia's own partnerships of investment and education providers and is an achievable and productive model for Australia to emulate. Purdue doesn't have the same historical experience in engaging with the semiconductor industry or manufacturing facilities that ASU does. Instead, it offers a strong R&D and innovation ecosystem that provides an incentive for industry partnership that Australia can learn from.

Australian universities have similar strengths as Purdue in R&D capability, which they can use to attract investment, commercialise innovation and develop curriculums that address the human-capital challenge. That investment will bring with it access to industry expertise that will enable Australian universities to scale their semiconductor education programs and grow a talent pipeline that supports manufacturing.

The effectiveness of the Purdue–SkyWater model is inspiring similar initiatives between the semiconductor industry and universities in the US such as Ohio State, the University of Michigan, Syracuse University, Oregon State University and the University of Texas. Participating companies include the likes of Intel, Nvidia and Samsung.

Case study 4: Taiwan's approach to talent-pipeline development through PPPs

Taiwanese policymakers have implemented major talent-development initiatives that use PPPs between industry, academia and government institutions to ensure the longevity of the country's semiconductor-manufacturing sector, which is the largest in the world.

Drivers of the partnership

Semiconductor talent is at the top of the list of national priorities for Taiwan, as the capacity for Taiwan's industries to meet its labour-pipeline demands will determine the longevity of the nation's global leadership in the world's most critical technology. In 2022, some 33,000 job vacancies for engineers and other technical positions went unfilled.¹⁰⁰ Collaboration through PPPs between industry, government and academia is viewed as the most effective holistic approach to addressing the workforce-development problem.

Key activities

Government investment

Taiwanese policymakers have implemented major talent-development initiatives. In 2021, the Taiwanese Government committed more than US\$300 million over 12 years to establishing a network of semiconductor-focused graduate schools tasked to design specialised curriculums that produce engineers with the knowledge and skills required by TSMC, United Microelectronics Corporation, MediaTek and others.¹⁰¹

In mid-August 2023, Taiwan's National Technology Security Council launched a 10-year chip program, committing US\$274.14 million in the first year, with the intention of making Taiwan a global hub for integrated circuit design.¹⁰² The investment will fund overseas training bases to boost technology cooperation and grow the necessary skilled workforce required to support the Taiwanese chip industry. The focus on integrated circuit design will also enable countries with smaller semiconductor industries to build out a training base in a less capital-intensive stage of the semiconductor value chain and familiarise their industry with Taiwan's advanced capabilities. This is an example of an avenue for foreign direct investment in Australia's semiconductor industry that should be pursued in conjunction with the policy recommendations made on page 30.

Academic talent-pipeline development

Research and training centres and degree programs were set up at the National Taiwan University in Taipei, the National Cheng Kung University in Tainan, and National Tsing Hua University and National Yang Ming Chiao Tung University in Hsinchu City. Operating on a year-round schedule, those institutions are now in the early stages of producing a pipeline of thousands of students with specialised master's and doctoral degrees. Each of the new centres aims to graduate around 100–150 students in 2023, and to continue to scale up from there.

National Taiwan University, alone, has more than 50 members of faculty who teach and research semiconductors—one of the largest such concentrations of academics in the world.¹⁰³ Almost all faculty operate from within the computer science or electrical engineering departments.

To avoid crowding out other STEM-related priorities, National Taiwan University and its peers combine chip innovation and production with AI-based disciplines, such as computer learning, computer design, simulation and smart manufacturing. The Artificial Intelligence – National Taiwan University Centre, for example, funded by Taiwan's Ministry of Science and Technology, features graduate programs that focus on chip hardware and the study of neural networks and cognitive AI.¹⁰⁴ While semiconductors constitute the ground-zero in an all future-oriented college tech curriculum, there's spillover into disciplines affecting other industries of the future, such as electric vehicles and clean-tech, aerospace, med-tech, communications and, of course, AI and computing.

Industry-driven curriculum collaboration

Taiwan's semiconductor companies are a case study in how multinational enterprises must proactively work with local academics to develop curriculums. They offer students professional mentoring and hands-on experience in factory clean rooms and provide financial support to students so that they can devote 100% of their time to their studies. At National Yang Ming Chiao Tung University, which is one of Taiwan's primary chip schools, semiconductor manufacturers such as TSMC, MediaTek and the United Microelectronics Corporation provide generous scholarships to graduate students.

TSMC offers annual scholarships to PhD students worth approximately US\$16,000 per year over five years.¹⁰⁵ This covers courses in material science, electrical engineering and applied physics as well as more granular semiconductor-specific courses dealing with the design and manufacture of memory-, logic- and power-related chips and other nanodevices.

Meanwhile, Taiwan's world-leading contract manufacturers such as Wistron, Novatek Microelectronics and Foxconn (the primary producer of Apple's smartphones) provide proactive curriculum development.¹⁰⁶ Thus, a nexus between semiconductor-related education and smart manufacturing across a broad range of industries is achieved.

Two-way talent pipeline between industry and academia

Taiwan's chip schools owe much of their early development success to the recruitment of former corporate executives, who have then gone on to serve as college deans.

Burn Jeng-Lin, known as Taiwan's 'father of immersion lithography'¹⁰⁷ (a critical process for manufacturing microchips) was a vice president at TSMC before being appointed as the dean of National Tsing Hua University's College of Semiconductor Research.¹⁰⁸

Jack Sun, another former TSMC senior executive, became the dean of the Industry Academia Innovation School at National Yang Ming Chiao Tung University. Mr Sun guides an institution of research and learning that brings academics together with leading businesses. The idea is to connect, collaborate and innovate across different domains to create new breakthrough technologies.¹⁰⁹ Semiconductors are the key foundational technology, but the task is to also advance other emerging areas, from quantum computing to zero-carbon technologies.

Taiwan's chip schools are also increasingly teaming up with American and Japanese multinationals, such as Micron and Tokyo Electron.

Key takeaways for Australia

Taiwan's domestic approach to talent-pipeline development offers Australia an insight into the benefits that PPPs offer as a holistic strategic approach to growing the semiconductor-manufacturing industry. The clear national imperative and collective understanding across Taiwan's industry, academia and civil society of the importance of the semiconductor industry to national and economic security demonstrates how communication from the government is vital in incentivising engagement with the industry at all levels, particularly for students who will be studying to boost the talent pool.

Australia can also see how talent-pipeline development occurs in two directions: industry feeds into academia to provide leading-edge expertise to students. There are dual benefits of talent-pipeline development for adjacent technologies, such as AI and quantum computing. Australia's global credentials in quantum R&D and innovation should serve as an additional incentive for collaboration from industry and should be championed by Australia when it seeks to attract investment from foreign foundries.



Opportunities for Australia's semiconductor industry base

Talent-pipeline development in semiconductor manufacturing will require an industry to feed into to validate investment. Investment from the manufacturing industry in Australia is also necessary to attract skilled individuals with the expertise to enable Australian universities to grow their curriculums. Australia's development of its semiconductor industry should be viewed as a positive-sum initiative within the broader ecosystem of capable semiconductor-manufacturing nations with aligned values. The foundries located in those nations are the entities from which Australia is attracting investment, and friend-shoring talent and manufacturing will strengthen supply chains.

A consistent theme in the successful PPPs highlighted in our case studies is the importance of a collaborative and holistic ecosystem approach from policymakers, industry and academia. The case studies also highlight an awareness of each sector's unique strengths and role within the semiconductor-manufacturing industry and the shared benefits of supply-chain security.

Australia's states and territories will need to lead in championing the strengths of their industrial and academic systems and develop incentives for investment from foreign manufacturers. At the federal level, policy that signals support for semiconductor-manufacturing investment, talent-pipeline development and the allocation of funding for industry development will be vital.

Australia, through its advanced university and government-agency semiconductor R&D facilities, enterprising start-up companies, infrastructure, skilled jobs focus, investment in critical technologies and talent pipelines by both federal and state governments, is well positioned to participate in the global semiconductor value chain. Beyond chip design, several states have credentials to attract and support (friend-shore) commercial foundries to manufacture chips and facilities to package them into products. As a nation, it's important that we take this step.

Sustainability and infrastructure considerations must also be considered when developing a semiconductor industry. Stable electricity, clean water and desalination plants are required to support manufacturing along the value chain. From a renewables perspective, solar is the fastest growing electricity generation type in Australia and supplied 10% of Australia's electricity in 2020–2021.¹¹⁰ The Australian Renewable Energy Agency has worked closely with industry on adopting renewable energy in its activities. Australia is ranked 6th globally for renewable attractiveness and aims to be a major exporter of renewable energy by 2030,¹¹¹ which signals energy security and sustainability to a semiconductor industry looking to invest and provides competitive advantage.

As an economy heavily reliant on mining, which similarly requires significant volumes of water, and as an ecosystem prone to natural droughts, Australia has strongly innovated in water efficiency and management.¹¹² The following examination of the NSW and Queensland ecosystems is intended to highlight the development potential for those states to serve as the industry base for Australia's domestic semiconductor-manufacturing capability. Victoria and South Australia also have strengths, and similar analyses could be assembled for them. This examination is also intended to draw policymakers', industry's and academia's attention to their role within the moonshot and highlight avenues for collaboration.

Statistics for Western Sydney, NSW and Queensland provide tangible evidence that Australia has significant assets in major infrastructure, R&D facilities, education, training and industry. These examples provide a strong case that Australia is more than capable of being a participant, not just a customer, in the global semiconductor-manufacturing value chain. The intention is to demonstrate the current breadth of activities occurring in NSW and Queensland across government, research communities and industry, which could be further enhanced through PPPs in aid of the semiconductor moonshot.

Semiconductor manufacturing, design, packaging and training in NSW

Western Sydney 24/7 Passenger and Freight International Airport

Western Sydney Airport Co. Limited, which is owned by the Australian Government, is building the Western Sydney 24/7 Passenger and Freight International Airport with a \$5.3 billion commitment. The airport will provide direct connections to overseas markets, enhancing Western Sydney's connection to world economies. The airport site at Badgerys Creek is located near the NSW Government's Western Sydney Employment Area,¹¹³ the Western Sydney Airport Growth Area¹¹⁴ and the Southwest Growth Area.¹¹⁵ On track for 2026, it will attract investment in business in Western Sydney, ranging from manufacturing and logistics to education and other professional services. The Australian and NSW governments are constructing new and upgraded roads around the airport under the \$4.1-billion Western Sydney Infrastructure Plan.

Western Sydney City Deal

A 20-year partnership agreement has been formed between the Australian, NSW and eight local governments to create the 'Western Parkland City'. This involves delivering rail, jobs, educational opportunities and community infrastructure to support Western Sydney's growth. Key commitments are:

- joint Australian and NSW Government funding and delivery of Stage 1 of the Sydney Metro – Western Sydney Airport (North–South Rail Link), from St Mary's to the Western Sydney Aerotropolis via the Western Sydney 24/7 Passenger and Freight International Airport, for which the Australian Government has announced \$5.25 billion towards the delivery of the rail line
- a \$190 million Western Parkland City Liveability Program to deliver community facilities
- a \$30 million Western Sydney Housing Package.

Western City Parkland Authority advanced manufacturing and talent pipeline

The Western City Parkland Authority and the NSW Vice Chancellors' Committee have formalised an agreement to boost education and research across the Western Parkland City. The committee includes the vice-chancellors of 14 universities in NSW and the ACT. The agreement is focused on research in advanced manufacturing technology. It will be centred on the Advanced Manufacturing Research Facility being developed in Bradfield City Centre—Australia's newest city centre in the heart of the Aerotropolis.

The Advanced Manufacturing Research Facility will bring industry and universities together, alongside the CSIRO, to access the latest technologies and research in advanced electronics and manufacturing, including robotics, additives and automation. The agreement includes the NSW Government's \$37-million New Education Training Model. The model is being delivered by Western City Parkland Authority in collaboration with industry, universities, vocational-education and training providers and government. Industry-led and designed to fill the gaps in traditional training, it allows businesses to create specific short courses to plug gaps in workforce training in new and emerging industries.

NSW Semiconductor Sector Services Bureau

Supporting economic growth across critical local industries including health, defence and communications, the NSW Semiconductor Sector Services Bureau (S3B) will enable advances in semiconductor technologies, connecting companies, researchers and capabilities to accelerate their global commercial impact. S3B brings together leading experts from the University of Sydney, Macquarie University, the University of New South Wales, CSIRO, the ANFF and industry partners from across the sector. Its mission is to enhance Australia's semiconductor capabilities and increase Australia's participation in the global semiconductor market.

Sydney Quantum Academy and centres of excellence

Sydney is home to world-leading universities and one of the highest concentrations of quantum experts globally. Semiconductor technology know-how is at the heart of that expertise. In its universities, Sydney has the largest pool of STEM graduates in Australia. More than 40,000 students are enrolled each year in science,

engineering and IT degrees. Sydney Quantum Academy offers quantum-specialised units and courses, research projects and work-integrated learning, incubating start-ups and accelerating entrepreneurialism.

NSW also hosts the state node of Australian Research Council (ARC) centres of excellence, notably the Centre of Excellence for Future Low-Energy Electronic Technologies (FLEET), the Centre of Excellence for Engineered Quantum Systems (EQUS), the Centre of Excellence for Quantum Computation and Communication Technology (CQC2T) and the Centre of Excellence for Exciton Science, all of which engage in adjacent R&D within the university ecosystem. They're key attractors for industry looking to invest and partner with capable research facilities and ensure access to the associated talent.

Australian National Fabrication Facility NSW node

Split between the University of New South Wales (UNSW) and the University of Sydney, ANFF NSW has extensive clean-room, CS and Si-MOS technical capability. ANFF activities at UNSW include Si-MOS and gallium arsenide devices with sub-50-nanometre features, encompassing quantum computing, biomedical devices, nano-photonics, medical detectors and photovoltaics. ANFF NSW equipment at the University of Sydney is part of the Research and Prototype Foundry, which enables the development of optical chips, electronic devices and new quantum science and technology. In NSW, ANFF has both a materials node (University of Wollongong, University of Newcastle) and an opto-fab node (Macquarie University, University of Technology Sydney, University of Sydney). ANFF's ACT node (Australian National University) is closely linked to this activity and has complementary expertise.

Semiconductor manufacturing, design, packaging and training in Queensland

Australian National Fabrication Facility Queensland node

ANFF-Q activities are split between the Australian Institute for Bioengineering and Nanotechnology and the Centre of Organic Photonics and Electronics at the University of Queensland, and the Queensland Micro- and Nanotechnology Centre and Queensland Microtechnology Facility at Griffith University. ANFF-Q has clean rooms that meet ISO 4, 5, 6 and 7 standards, world-leading expertise and IP in compound semiconductors for silicon carbide, device designs for gallium nitride UV-LEDs, and novel gallium oxide technology. ANFF-Q provides professional training and facilities for fabrication, applying nanoscale 3D printing, desktop 3D printing, photolithography, deposition and etching techniques for the creation of thin films and nanostructures in semiconductors, and microfluidic devices.

Queensland university ecosystem

Queensland has a strong university ecosystem with research capabilities in semiconductors, process development, microelectronics, nano- and micro-technologies, photonics and quantum technology. Griffith University, the Queensland University of Technology, the University of Queensland and the University of Southern Queensland also have infrastructure-sharing arrangements, in which businesses that elect to work with one university are able to access facilities and researchers across the sector and their experience in commercial partnerships. The relationship between ANFF-Q, Queensland universities and industry also holds strong foundational potential to develop the talent pipeline to support a scaled manufacturing capability through similar PPPs.

Queensland centres of excellence and industry activities

Queensland hosts nodes of four centres of excellence that provide a foundation of R&D expertise in semiconductors and adjacent technologies such as quantum, which offer ideal investment and partnership opportunities for universities and industry. The state nodes of the ARC EQUS, the ARC CQC2T, the ARC FLEET and the ARC Centre of Excellence in Quantum Biotechnology (QUBIC) all provide incentives for collaboration

with semiconductor-manufacturing partners and a foundation for talent-pipeline growth through collaboration on curriculum development, R&D and innovation scaling.

Silanna Group

Silanna Semiconductor is a US company headquartered in San Diego, California, with global facilities, including in Brisbane. Silanna Group supplies high-tech chips to customers in the global communication, defence, medical and space industries, specialising in UV light emitters and detectors, power switches and RF integrated circuits. Silanna Group also has patented device designs for gallium nitride UV-LEDs. Its capability and existing customer base could be scaled up through investment and partnership with R&D and innovation activities at universities. This is a case of a talent pool already located in Australia that can be used to attract manufacturing investment that complements design activities.

State government strategy and investment

In July 2023, the Queensland Government announced the development of the Queensland Quantum and Advanced Technologies Strategy. The government has recognised the strategic importance of semiconductor and advanced manufacturing, and its relationship with emerging technologies, notably quantum, for which Queensland has strong R&D and innovation capability. The government has invested \$520 million through the Invested in Queensland program, which focuses on unlocking new investment through partnerships with the private sector and is key in signalling domestically and globally the opportunities to develop PPPs in Queensland. The program is part of the government's effort to scale up Queensland's semiconductor ecosystem through partnership with industry. The ultimate aim is to develop a pilot-scale to low-volume fab that brings manufacturing onshore for existing businesses and supports new businesses.

The ecosystem of chip companies: potential private partners for Australia

There exists a strong ecosystem of chip companies, particularly US-based entities that, when paired with the right Australian partners in defence, industry and academia, have the potential to achieve the ambitions laid out in the moonshot. In the immediate term, Australia needs to focus on attracting investment from mature chip companies (as opposed to advanced chip foundries) in order to grow the domestic industry. Table 1 is a snapshot of a range of potential chip-company partners and their size, operations, niche technological outputs and strengths, and potential compatibility with the proposed Australian-based semiconductor foundry entry point at mature-process scale.

Table 1: Potential partner examples

Company	Specialty	Location
SkyWater Technology Foundry	Provision of semiconductor development and manufacturing services	Minnesota, US
Deca Technologies	Pure-play developer and manufacturer of miniaturised wafer packaging	Arizona, US
Lansdale Semiconductor Inc.	Semiconductor aftermarket manufacturer with a focus on legacy chips	Arizona, US
Wolfspeed	Materials manufacturing and silicon carbide fabrication	New York, US
Vishay Intertechnology	Manufacturer of discrete semiconductors and passive electronic components	Pennsylvania, US
SK hynix	Semiconductor foundry with chip design and R&D capabilities	South Korea
GlobalFoundries	Semiconductor manufacture and design company	New York, US

Recommendations to support the national semiconductor moonshot

The NSW and Queensland examples, together with strengths in other states, serve as a tangible opportunity in which Australia can develop the PPPs required to enable a national moonshot and secure talent pipelines for the industry.

Beyond investment and reducing entry barriers to industry, it's critical that semiconductor curriculums are developed in line with commercial and defence priorities and needs. Contrary to what sceptics may fear, this doesn't require the abandonment of Australia's rich legacy of liberal arts, freedom of expression and open learning. Australia can and should continue to emphasise those priorities while adjusting to today's geopolitical realities.

The nine policy recommendations in Table 2 are intended to support the manufacturing moonshot investment, with an emphasis on talent-pipeline development. They're in addition to the 10 recommendations made in our 2022 ASPI report.

Table 2: Policy recommendations in support of the national semiconductor moonshot and talent-pipeline development

	Recommendation	Responsible for implementing	Responsible for funding	What purpose will it achieve?
1	Develop a semiconductor moonshot strategy with links to existing advanced technologies, capabilities and strategies, including quantum computing and AI. Outline a road map for priority investment areas, state government opportunities, and industry and academia incentive programs.	Federal government	Federal government	This will demonstrate strategic leadership and signal semiconductors as a priority investment area for global industry, academia and states. It will also draw a public connection between semiconductors as a priority advanced-technology goal in relation to defence and national security.
2	State-government delegations with representation from relevant academic and industry organisations should visit and establish partnerships with semiconductor-manufacturing firms and universities engaged in PPPs, as highlighted in the case studies. US partners should be prioritised due to the combined benefits of their global leadership in manufacturing and incentives to collaborate to secure semiconductor supply chains within the US–Australia alliance. However, opportunities such as Taiwan's overseas training hub in integrated circuit design should also be pursued.	State government	State government	This will enable practical engagement and relationship building with industry and academia in semiconductor manufacturing and talent-pipeline development. It presents an opportunity to leverage advice and identify areas for collaboration with Australian academic, government and industry partners.
3	Pursue targeted government-to-government collaborative talent development under the auspices of AUKUS and the Five Eyes and, to a lesser extent, through the Quadrilateral Security Dialogue and other secure-supply-chain initiatives.	Federal and state governments	Federal and state governments	This will use established networks to identify shared gaps in semiconductor manufacturing and talent supply chains and coordinate resource sharing to address them.
4	Mandate inclusive and diverse intake of candidates in all key chip programs, from across the entire Australian population.	n.a.	Universities	This will assist in maximising the scale and depth of the national semiconductor talent pool.

5	Create secure, high-value partnerships between industry, academia and governments to share in the funding and strategic development of semiconductor curriculums at the BSc/Eng, MSc/MEng and PhD levels that are relevant to the semiconductor industry's needs.	Government coordinated, requiring equal participation from academic and industry entities	Joint funding from government, industry and academia incentivised by shared benefits of talent-pipeline development	This will create more avenues for high-skilled workforce development and ensure that curriculums are tailored to the needs of Australia's semiconductor industry.
6	Establish a national fund for K-12 STEM proficiency to fast-track learning and upskilling of human capital, for both secondary and vocational training.	Federal government	Federal government and industry	This will aid in long-term talent-pipeline security by ensuring that larger numbers of students are educated early in STEM fields necessary to support the semiconductor industry.
7	Link Australian semiconductor curriculums to sustainable technology and specialised niches of emerging businesses, including communications, electric vehicles, med-tech and defence.	State governments and universities	State governments and universities	Emphasis on adjacent technology pipelines will strengthen Australia's technology leadership and supply-chain security.
8	Implement visa programs that encourage and support talent friend-shoring within alliance frameworks and include the development of complementary socio-economic ecosystems that help to minimise culture shock for expats.	Federal government	Federal government	This will enable talent pool friend-shoring within trusted alliance networks and attract skilled workers needed to support Australia's semiconductor industry.
9	Universities should engage semiconductor-industry boards to review and adjust curriculums where appropriate to strengthen education and talent-pipeline development.	Universities and industry	Universities and industry	This ensures that education is meeting commercial needs in critically important sectors.

Australia is undergoing a period of significant defence and strategic technology review, and semiconductors need to be included in that conversation. Signalling from government has indicated that leadership in emerging technology sectors is critical to Australia's national security. Semiconductors are vital in achieving that, so it's critical that we lay the foundations for long-term supply-chain security through the establishment of the manufacturing, design and packaging capabilities outlined in the national semiconductor moonshot.

Leveraging existing investment policies, such as the NRF, growing nascent industry capabilities such as the S3B, upscaling the ANFF to pilot production capability and learning from allies and partners successfully using PPPs to address talent-pipeline security are all central to Australia's success. The moonshot will require bold commitment from the Australian Government and active participation from the states.

This report has aimed to show how policymakers, industry and academia can pivot from the conventional logic that, in order to establish a foundry capability, all we can do is to use the critical mass in the existing chip-manufacturing ecosystem. If a fully developed ecosystem doesn't already exist, according to such logic, any attempts to create one from the ground up would be futile. We beg to differ. Instead, there's a clear pathway to achieving the semiconductor-manufacturing moonshot through a 'if you build it they will come' approach. This will require significant coordinated commitment of public and private resources and partnerships. It's not only possible, but necessary, to secure Australia's interests for generations to come.

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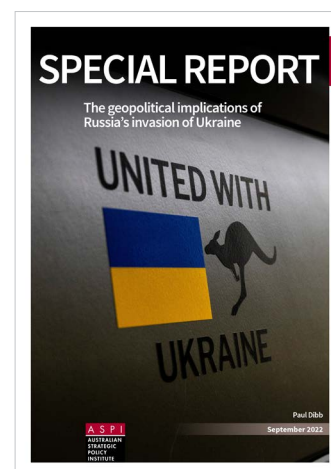
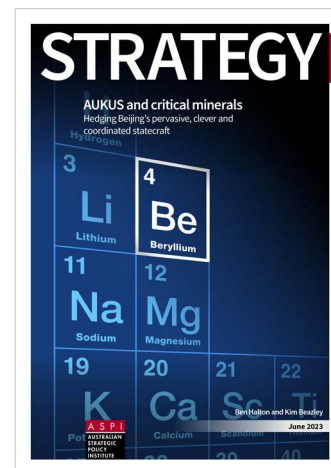
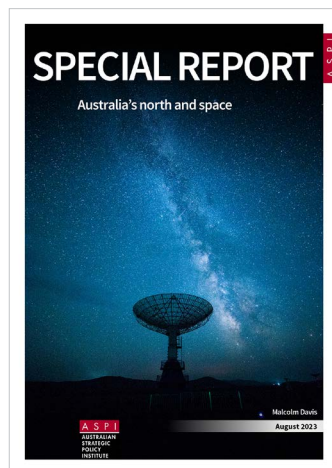
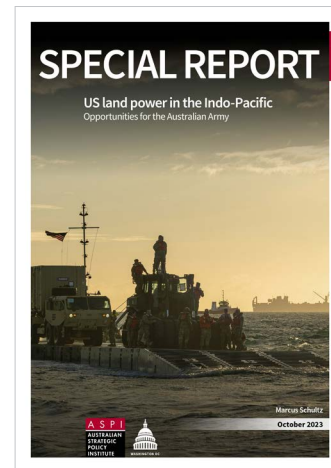
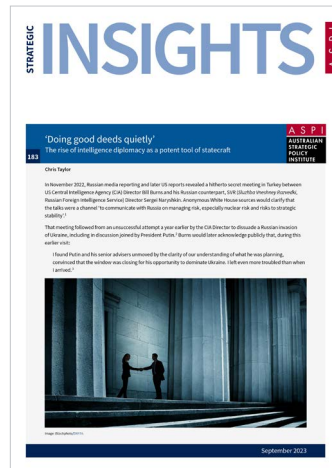
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Acronyms and abbreviations

AI	artificial intelligence
ANFF	Australian National Fabrication Facility
ARC	Australian Research Council
ASCA	Advanced Strategic Capabilities Accelerator
ASU	Arizona State University
CHIPS Act	Creating Helpful Incentives to Produce Semiconductors and Science Act (US)
CMOS	complementary metal-oxide semiconductor
CS	compound semiconductor
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DISR	Department of Industry, Science and Resources
DSR	Defence Strategic Review
EQUUS	ARC Centre of Excellence for Engineered Quantum Systems
IIT	institute of technology
IP	intellectual property
IT	information technology
NRF	National Reconstruction Fund
PPP	public-private partnership
R&D	research and development
S3B	Semiconductor Sector Services Bureau
Si-CMOS	Silicon complementary metal-oxide semiconductor
STEM	science, technology, engineering and mathematics
TAFE	technical and further education
TSMC	Taiwan Semiconductor Manufacturing Company
UPWARDS	University Partnership for Workforce Advancement and Research and Development in Semiconductors
UV	ultraviolet

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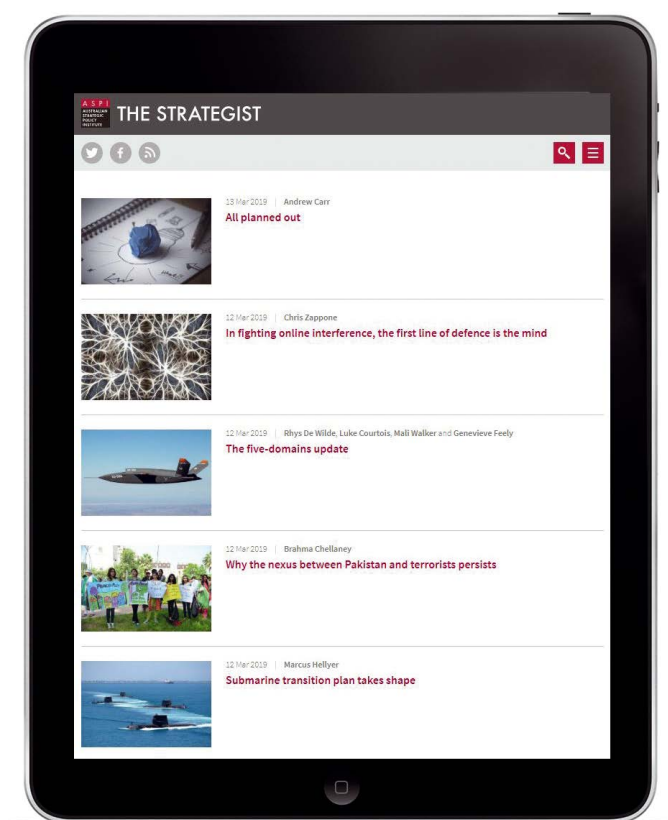


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