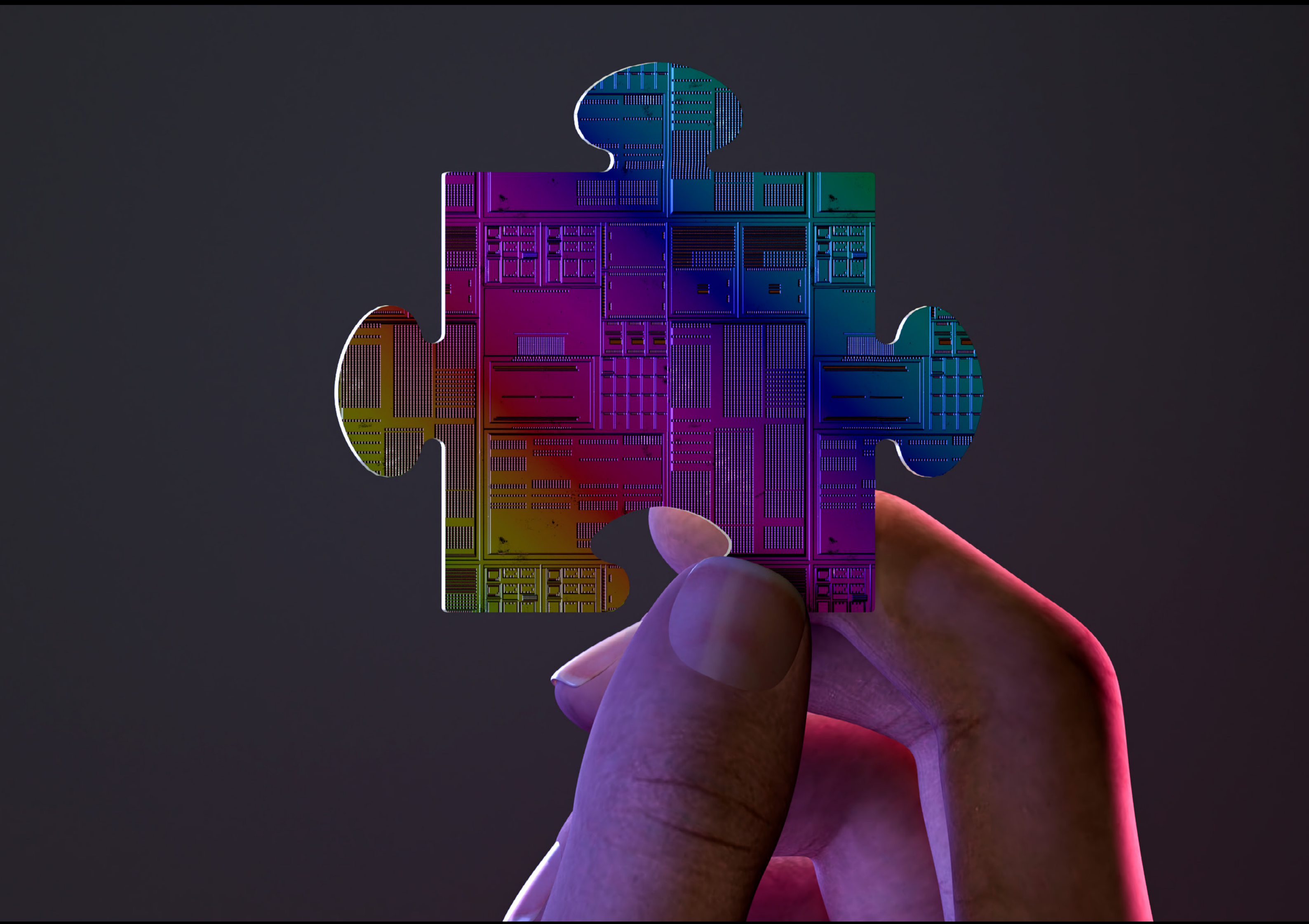
Australia's semiconductor national moonshot

Alex Capri and Robert Clark



ASPI AUSTRALIAN STRATEGIC POLICY INSTITUTE
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Policy Brief
Report No. 63/2022

About the authors

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Robert Clark was formerly an officer in the Royal Australian Navy, a lecturer and Fellow of The Queen's College at the University of Oxford, and Scientia Professor and Chair Professor of Experimental Physics at the University of New South Wales. As an inaugural Australian Government Federation Fellow, he was the founding Director of the ARC Centre of Excellence for Quantum Computer Technology over its first decade. More recently, he was Chief Defence Scientist in the Australian Department of Defence, CEO of the Defence Science and Technology Organisation and a member of Australia's Defence Committee. In that role, which took him to Afghanistan on several operationally focused visits associated with force protection, he was the Australian Principal of the Technical Cooperation Program between Australia, the US, the UK, Canada and New Zealand and a member of the Prime Minister's Science, Engineering and Innovation Council. He's a Fellow of the Australian Academy of Science and a Distinguished Fellow of the Royal Society of New South Wales and is currently a Senior Fellow at ASPI. He's been privileged to receive a number of awards and honours, which include the Australian Museum CSIRO Eureka Prize for Leadership in Science, the Australian Centenary Medal, the Australian Defence Medal, the United States of America Secretary of Defence Medal and two medal awards for distinguished service from US Government agencies and is an Officer in the Order of Australia.

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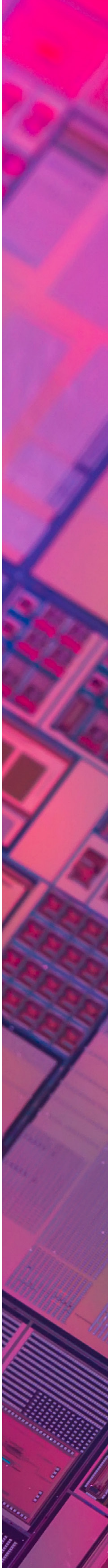

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Foreword

Australia has recently been forced to cross a Rubicon. Its wholehearted embrace of global free trade and just-in-time supply chains has had to confront the hard reality of geopolitics. In many parts of the world, geopolitics is choking free trade, and China—Australia's largest trading partner—has shown itself particularly willing to use trade coercively and abrogate its free trade commitments, not just with Australia, but with countries all around the world.

Advanced technologies are at the centre of this geopolitical struggle, because of the risk that withheld supply poses to national economies and security. As Covid-19 disruptions have demonstrated, the risks are not even limited to deliberate coercion.

In this environment, bold action is warranted. Continuing to do what we did before is not an option because it will undermine the national interest. A new approach is needed that's in part heretical to our old market-based approach but is driven by necessity: government intervention that works in tandem with industry expertise and drive.

In this important policy brief, Alex Capri and Robert Clark lay out a vision for Australia to secure its place in the global semiconductor industry—an industry they describe as 'the single most important technology underlying leading-edge industries'.

Their proposal is to stimulate A$5 billion of semiconductor manufacturing activity through A$1.5 billion of government investment and financial incentives. Those subsidies and tax concessions would mirror similar initiatives such as the US 'CHIPS' and 'FABS' Acts, but are focused on Australia's interests.

They identify a logical niche for Australia that would initially establish a distributed commercial compound semiconductor foundry capability across Australia via a public–private partnership. In the longer term, they propose establishing a commercial silicon complementary metal-oxide semiconductor foundry at mature process scale.

Government intervention in a market shouldn't be made lightly, but Capri and Clark make a compelling case to do so. If policymakers agree that Australia needs access to semiconductors and that their supply from elsewhere can't be guaranteed, then intervention is imperative.

This policy brief lays out a 'moonshot' to get Australia there.

Fergus Hanson
Director, International Cyber Policy Centre

What’s the problem?

Semiconductors (also known as ‘microchips’ or ‘chips’) are the single most important technology underpinning leading-edge industries. They’re essential for the proper functioning of everything from smartphones to nuclear submarines and from medical equipment to wireless communications.

Australia’s notable lack of participation in the global semiconductor ecosystem has put it at a geopolitical disadvantage. As a nation, with some niche exceptions, it’s almost entirely dependent on foreign-controlled microchip technology, making it increasingly vulnerable to global supply-chain shortages, shutdowns and disruptions. Such occurrences have become all too common, either because of events such as the Covid-19 pandemic or because of other governments’ attempts to weaponise supply chains for geopolitical reasons.

Having unfettered access to microchips is a matter of economic and national security, and, more generally, of Australia’s day-to-day wellbeing as a nation. In an increasingly digitised world, policymakers must treat semiconductors as a vital public good, almost on par with other basic necessities such as food and water supplies and reliable electricity—a reality that would become immediately apparent in a time of international crisis resulting from, for example, wars or natural disasters.

What’s the solution?

Australia must conceive, develop and execute a national plan that will enable capacity building in the semiconductor space. To do this, leadership must embrace bold thinking and adopt its own version of a 21st-century ‘moonshot’. Instead of landing astronauts on the Moon, however, as the Americans did in their own original moonshot in a Cold War space race against the Soviet Union, Australia faces an equally daunting task: from a low base, breaking into the world’s most complex, expensive and strategic technology ecosystem.

To achieve that, the Australian Government must do four overarching things.

First, it must embark on an epic technology-transfer initiative. To be successful, Australia must attract and absorb leading-edge technology, human capital (talent) and investment through a range of strategic partnerships with world-class companies, universities and friendly governments. The good news is that Australia already has a wealth of resources and building blocks to which it can turn to bring this to fruition.

Second, it must leverage its security partnerships and alliances with the US, Britain, Japan and others to tether the development of its semiconductor capabilities to evolving mutual defence needs and related innovation. Security alliances such as the Quadrilateral Security Dialogue (the Quad), AUKUS and the Five Eyes network must double up as enablers of Australia’s semiconductor sector (and other critical technology) advancement. The spillover to Australia’s commercial sector will be immense.

Third, Australia's firms and local talent must become enmeshed in global value chains. Not just any value chains, however. Australia's strategic industries must seek to secure supply-chain arrangements via bilateral, minilateral and multilateral agreements, and government should continue to participate in high-quality multilateral free trade agreements, assuming those agreements actually enforce rules and standards reflective of Australia's core values.

Countries such as the US, the UK, Japan and South Korea, along with various EU nations, India, Taiwan and Singapore, show good potential for 'friend-shoring', meaning that they could provide safe havens for the ring-fencing of Australia's strategic value chains. For example, Australia could join Washington's 'secure' ('China-free') supply-chain arrangements with Taiwan, Japan and South Korea as part of the US Creating Helpful Incentives to Produce Semiconductors and Science Act (CHIPS Act) or pursue similar agreements with the EU's nascent supply-chain security agreements as part of the EU's European Chips Act. Bilateral and minilateral agreements are preferred. Such an outcome would be mutually advantageous to all parties, given the benefits of rationalised global value chains for the world's most complex sector.

Highly specialised slices of the semiconductor value chain require a dizzying range of materials, processes, equipment and technologies from trading partners that must be relied upon to deliver the goods without the risk of sanctions, blacklists and export bans—or any other geopolitically motivated weaponisation of supply chains. Every niche player in Australia's microchip ecosystem, therefore, must keep its critical production activities ring-fenced within 'friendly' geopolitical and geographical value chains.

Strategic friend-shoring and home-shoring must cover everything from localised rare-earth and critical-materials processing at the bottom of supply chains to the production of specialised microchips at the top end.

Fourth, Australia's public sector must step up to facilitate the right kinds of public–private partnerships (PPPs), provide targeted funding for semiconductor R&D and education, and create commercial incentives for foreign and local investments. This will require adept 'techno-diplomacy' with foreign partners, as well as a deft touch regarding the local technology landscape, as too much government interference could impede Australia's tremendous entrepreneurial spirit. This is a moonshot: big and bold actions and expenditures are needed, not overly cautious gradualism.

Executive summary

In this report, we set out to make specific recommendations underpinning an Australian semiconductor national plan. This is an urgent task, which is presented in a global context, with special emphasis given to the geopolitical complexity of semiconductor supply-chain issues and Australia's important strategic alliances and partnerships.

Our analysis emphasises the centrality of a commercial semiconductor chip manufacturing capability, which is nearly absent in Australia. Developing other aspects of the semiconductor ecosystem is important, including critical minerals and microchip design, but those areas must be addressed concurrently, as part of a larger, decisive plan, not through a gradualist approach. Opting out of semiconductor manufacturing will severely constrain Australia's growth as a technological nation and consign it to second-tier status.

International examples, and recent substantial incentives formalised by governments worldwide for this critical industry, such as the US and European 'Chips' Acts, are highlighted and provide guidance.

Australia has an R&D semiconductor fabrication foothold upon which it can build its new capabilities. Viable investment streams via the Australian National Fabrication Facility (ANFF) network under the National Collaborative Research Infrastructure Scheme must be increased substantially.

A sufficiently funded ANFF, with capability increased to pilot production in key nodes, could underpin closely located foundries via public–private partnerships (PPPs) with commercial manufacturing firms. As is the case for PPP developments in the US and UK, it's proposed that Australia attract appropriately tailored foundry capability in compound semiconductors, and also in complementary metal-oxide-semiconductors (silicon CMOS) at mature process scale. The endgame is to address these key markets with a sovereign talent pipeline.

We provide a dollar amount estimate for that outcome, indicating a pathway to some A$5 billion of semiconductor manufacturing activity, stimulated by A$1.5 billion of government investment and financial incentives, including direct subsidies and tax offsets, which are part of that total.

As well as financial estimates, we address the issue of focus and the scale of an Australian semiconductor 'moonshot'. We also map the four overarching actions that we've outlined under 'What's the solution?' to quite specific recommendations. That mapping considers the current Australian semiconductor *status quo* to outline an existing foothold that Australia can sensibly build on. We also take note of significant US and UK government incentive schemes recently announced to strategically define and boost those countries' semiconductor industries and supply chains, which Australia could proportionately finetune to its comparative stage of development.

In a geopolitical context, we focus on the task of creating and executing an Australian national semiconductor plan. At its heart, and notwithstanding the importance of microchip design and marketing, the central and most complex issue that will define such a plan is building a sustainable, appropriately scaled, strategic market-penetrating, trusted commercial semiconductor fabrication capacity across Australia. With this focus, in laying out an analysis of the semiconductor landscape, we highlight topics that should be at the forefront of the national discussion.

Those topics include:

- concentrating on different business models and capacity-building scenarios, including the medium-term consideration of 'pure play' manufacturing of compound semiconductors as well as connected 'fabless' activities in research, design and innovation
- over the long term, exploring the merits of the 'integrated device manufacturing' model and silicon chip fabrication at an appropriate entry point
- focusing on specialised chip production for a growing range of sectors, including the automotive, medical, communications, energy and defence sectors
- recognising the importance of so-called 'trailing-edge', 'mature' chip technologies and why they're as important as 'leading-edge' semiconductors, in an economic and geopolitical context
- understanding the enabling role of trusted PPPs involving Australian and other leading universities and public-sector technology agencies, semiconductor companies and governments
- understanding the importance of technology transfer via defence-related alliances such as AUKUS and the Five Eyes and the role of government-funded research agencies in that transfer.

Geopolitical developments: semiconductors and techno-nationalism

Australia's semiconductor moonshot must be viewed in the framework of a wider historic paradigm shift. Economic liberalism and mostly unrestricted free trade have given way to the less optimal but necessary practices of 'managed trade' and the pragmatic application of techno-nationalism.[1] This phenomenon has been driven by geopolitics, largely as a reaction to the rise of China's state-centric and mercantilist economic model, which has basically up-ended the post–World War II rules-based trading system.

Global value chains (GVCs), therefore, will continue to decouple, fragment and 'localise', not only because of geopolitics, but also as a reaction to supply-chain problems resulting from the Covid-19 pandemic. Climate change will further accelerate fragmentation, as governments look to shorten and localise global supply chains as part of their decarbonisation efforts.

Global semiconductor initiatives

In the semiconductor landscape, the US, the companies of which remain a dominant force, has embarked on a national effort to re-shore the bulk of foreign outsourced chip manufacturing. In July 2022, the US Congress passed its CHIPS Act legislation, which provides US$52 billion in subsidies for the national semiconductor sector, plus another US$170 billion for technology and scientific R&D and innovation in areas such as 5G wireless, artificial intelligence and quantum science,[2] all of which are themselves heavily dependent on advanced semiconductor chips.

Other countries have rapidly followed the US example. The European Union passed its own CHIPS Act worth €43 billion.[3] Japan has stepped up efforts to upgrade its domestic semiconductor ecosystem by authorising US$6 billion, which includes subsidies to pay for the Taiwan Semiconductor Manufacturing Company (TSMC) to build a chip manufacturing plant with Sony.[4] South Korea has committed a whopping US$450 billion to turn its domestic landscape into a global semiconductor hub by 2030.[5]

India, which is not yet a player in the semiconductor space, is looking to get the world's top chip makers to build plants there. New Delhi's national semiconductor plan has four different funded initiatives that focus on a broad spectrum of the semiconductor ecosystem, including chip design and chip manufacturing capabilities.[6] New Delhi sees its role in the Quad and its strategic decoupling from China as selling points.

China, meanwhile, continues to struggle with its dependence on foreign-made leading-edge chips and related equipment for semiconductor manufacturing, although there are recent caveated reports on sovereign advances,[7] and has doubled down on efforts to fund the progression of its own semiconductor initiatives, including 'Made in China 2025'. Beijing's 14th Five-Year Plan, announced in 2021, named technology development as a national security issue and local semiconductor capacity building as a top priority under the Chinese Communist Party's broader 'dual-circulation' national self-sufficiency programs.[8]

Australia's unique attributes

Sceptics would argue that Australia's economy and market are too small, its geography too far removed from the world's other technology hubs, and its markets too dependent on, for example, agriculture and mining, for it to have a chance to participate in highly sophisticated semiconductor GVCs, let alone produce microchips in Australia.

Similar things were said about Ireland in the early 2000s and after the global financial crisis in 2009, as it steadily transformed itself from a mostly agricultural economy to a nation that boasts Europe's fastest growing technology hub, located in the aptly named 'Silicon Docks' area of Dublin. Despite recently raising corporate taxes, Ireland has created a talent pool of some 7,000 tech professionals through partnerships with local universities and multinational firms. Silicon Docks serves as a magnet to the world's top technology companies, large and small.

Taiwan, in the 1970s, similarly transitioned from an agricultural economy to become the world's microchip fabrication hotbed. Like Australia, Taiwan has maintained strong security ties with the US and has successfully leveraged the security relationship to achieve technology transfer and investment from the world's leading semiconductor players. The results were transformative on a historic scale. According to the Boston Consulting Group, Taiwanese companies now manufacture 60% of the world's microchips and 90% of the most advanced leading-edge chips. Given the threat of a forced unification with mainland China, the near-monopoly has become untenable.

In August 2022, Beijing's military incursions into Taiwan's territorial waters and the encirclement of the island through a series of 'war games' and other provocative actions have made one thing clear: the restructuring and diversifying of single-sourced semiconductor supply chains out of Taiwan is a geopolitical imperative.

This provides an important window for Australia, but it must move forward quickly and decisively. It must build its capabilities in this critically important technology that underpins the digital world. It must advance the complexity of its economy by targeting market share matched to its strengths for national resilience and develop a pipeline of talent with essential know-how for future industries. Opting out of semiconductor manufacturing would severely constrain Australia's growth as a technological nation and consign it to second-tier status.

Australia has excellent attributes that few other nations possess, and they can enable the achievement of a bold national semiconductor plan. Its local institutions, for example, are highly valuable assets. They include a robust and local financial system, a strong network of universities and R&D institutions, capable and transparent federal and state governments, and a host of entrepreneurial stakeholders in the business sector.

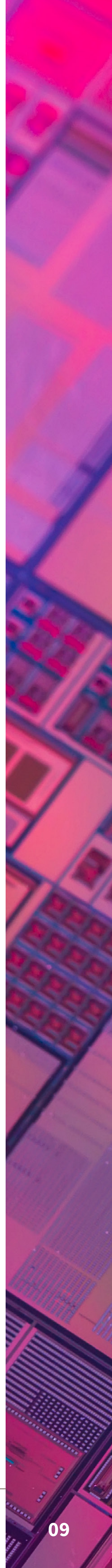
Through its techno-diplomacy options, the Australian Government has access to government-to-government, government-to-business and business-to-business partnerships with the world's leading semiconductor powers, both qualitatively and quantitatively. Thus, Australia's Department of Industry, Science and Resources (DISR) and Department of Defence are well positioned to drive key semiconductor initiatives spanning the public and private sectors.

New technologies have also lowered barriers. The 4th industrial revolution's diffusion of artificial intelligence (AI) and connectivity technologies rapidly levelled the global playing field for China's technocrats, and it can and should be a major power-multiplier for Australia. Specifically, the rapid diffusion and transfer of technology, both data and knowledge, at scale makes possible the swift transformation of an industrial sector or even an entire economy, as in no other time in history.

The new geopolitical paradigm has spawned a kind of innovation mercantilism that has created new tensions and contradictions between market forces and state actors. It would be misguided and counterproductive for any market economy to try to replicate Beijing's state-centric economic model in the pursuit of a national semiconductor plan. It would be equally dangerous to leave its development entirely to the market. That has clearly failed.

Therefore, a healthy equilibrium must be achieved that combines Australia's entrepreneurial and innovative market-driven energy with well-informed and proactive policymaking, together with its planned execution, particularly in the pursuit of new PPPs.

Australia has more than a fighting chance to absorb, deploy and scale up new technologies, investments and people into its own local semiconductor landscape.



Literature review: the current Australian semiconductor landscape

This study examines and builds upon a series of reports regarding the Australian semiconductor sector.

NSW Government: Semiconductor study

One groundbreaking report, commissioned by the NSW Government Chief Scientist and Engineer (NSW CSE),[9] was completed in December 2020 by the University of Sydney's Nano Institute[10] and the Maltby Group.[11] This comprehensive report examined the status and capabilities of Australia's semiconductor landscape and the nation's potential to participate in semiconductor GVCs.

The study drew upon focused interviews and discussions with some 100 individuals, companies and government agencies, together with extensive secondary research. While the report touched upon the importance of Australia's R&D and innovative capabilities via world-class universities and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), together with specific capabilities at the Australian Nuclear Science and Technology Organisation, related to the semiconductor value chain, it focused primarily on the commercial sector.

Integrated manufacturing and 'pure play' models

In this context, the report laid out the structural bifurcation of the global semiconductor business model and highlighted two distinct models:

- the integrated device manufacturing approach in which the design, manufacture and sales of chips occur within one company (such as Intel)
- the ascendant model of pure-play manufacturers, such as TSMC.

Under the pure-play model, TSMC provides fabrication services to many hundreds of 'fabless' chip companies. Fabless companies, such as AMD, NVIDIA and Qualcomm, primarily focus on the design and marketing of chips and leave fabrication to other entities.

Regarding both models, the overarching observation of the NSW CSE report was that, while there are pockets of boutique expertise and talent, in general, Australia's presence in the commercial semiconductor sector is shallow, considerably underdeveloped and notably fragile for an economy of its size and maturity, especially in fabrication capability.

Commercially, it was further noted that few Australian companies appear ready to compete globally and that they prefer to focus on domestic competition within niche 'end-use' sectors.

Australian strengths and building blocks

The NSW CSE consultation process did reveal notable pockets of Australian strength in semiconductor design capability, particularly in radiofrequency (RF), millimetre wave, photonics and radar. While 'application specific integrated circuit' design for RF communications (the backbone of all wireless systems) is largely focused on 5G and some specific Defence applications, there's also Australian capability in field-programmable gate array design and programming for mixed signal and data communications such as satellite communications, high-frequency trading, audio, video, radar, sonar and telemetry.

Composite semiconductors

There is, importantly, a further bifurcation of the semiconductor industry noted in the NSW CSE study, regarding semiconductor materials. Here the silicon primacy of complementary metal-oxide semiconductor (CMOS) platforms (roughly 90% of the sector overall is still silicon-based due to the maturity and scale of CMOS) is complemented by non-silicon 'composites' made of two or more elements, such as gallium arsenide, gallium nitride and indium phosphide.

While silicon dominates the processor and phone markets, these compounds are needed for a wide range of exacting end-use requirements in power electronics, RF communications, sensing and photonic applications. Australia has known reserves of these key materials and isolated examples of commercial production that represent a foothold in both design and prototype fabrication capability in composite (also referred to as 'compound') semiconductors currently geared to emerging, low-volume niche markets.

A visual summary of Australian status across the semiconductor value chain is provided by Figure 2 of the NSW CSE report, which catalogues some 60 commercial entities representative of Australian participation across input materials, design / intellectual property (IP), fabrication, packaging/ assembly/test/integration, sales/distribution/marketing, and end markets.

NSW CSE recommendations

The 2020 NSW CSE report contained key considerations and recommendations. The report set out a stepwise approach to capability and capacity building, including the establishment of a semiconductor sector service bureau and a semiconductor hub focused on supporting existing NSW and Australian semiconductor companies (especially in semiconductor design and IP, but also fabrication and assembly) to scale locally and better connect to and compete in international supply chains.

Such a brokering service to Australian fabless design firms should enable them to access semiconductor fabrication, packaging, assembly and test facilities globally together with market intelligence and linkages, via its coordinating role, and will be based in Sydney's Tech Central, with direct investment by the NSW Government.

Sydney's Tech Central partnerships

Sydney's Tech Central has so far attracted investment deals with local and foreign multinationals such as Atlassian, NEC and NTT, along with the country's National Space Industry Hub as tenants. The precinct is expected to be completed in 2025.

Proposed subsequent steps include a design centre and a mini composite fabrication plant. While Australia isn't well placed to enter the silicon CMOS market in its own right, encouraging Tier 1 and 2 fabricators to establish local facilities via various incentive packages is a smart strategy. Similarly, it's argued that an Australian composite foundry would require a joint venture partner or consortium with direct operating experience and a related co-design capability.

Beyond the NSW CSE report, there have been other noteworthy reports related to the Australian semiconductor sector.[12]

Australia's semiconductor narrative and pathway forward

The strategic importance of the semiconductor supply chain to Australia surfaced at the federal government level in the run-up to the May 2022 federal election.[13] Then Australian Prime Minister Scott Morrison announced that the Australian Government would devote A$324 million to expanding the Supply Chain Resilience Initiative (SCRI) if the Coalition were re-elected.

In the detail of that announcement was a small allocation of A$1.3 million to commission the Australian Chief Scientist, Dr Cathy Foley, to develop a national plan for semiconductors to address current and future supply. Further, A$27.3 million would be provided to 18 successful semiconductor and water-treatment-chemical projects under round 2 of the SCRI grants. Increasingly, the real-time application of data analytics and AI systems in the operation of water-treatment and large water-delivery systems requires specialised semiconductors.

Post-election, speaking at the Morgan Stanley Australia Summit in June 2022, Dr Foley touched on strategic considerations, including the impact of enabling technologies such as quantum computers and semiconductors on Australia's economic prosperity and security. In her address, which was covered by the *Australian Financial Review*, Dr Foley further commented on the enormous expense for the nation to build its own state-of-the-art semiconductor chip manufacturing facility and that establishing such a facility was far more complicated than simply having the financial resources to build one.[14]

Attracting a company to set up in Australia would require surety of talent, government incentives, reliable component supply chains and a host of other factors. While indicating that the government wasn't shying away from such a challenge, Dr Foley commented that it was worth doubling down on areas in which Australia is strong, namely semiconductor design and compound semiconductors.

Scaling up and expanding Australia's compound semiconductor capability

We concur with the view that Australia can achieve national capability in compound semiconductor design, and most importantly fabrication capacity, and propose that this can sensibly be achieved by leveraging a modestly sized but high-quality existing base of actors that extends into its public sector semiconductor investments. It remains to be settled whether future efforts should focus on a single pure-play foundry or a more distributed model, or both, but that should encourage more, not less, effort to raise the bar and move the semiconductor moonshot forward.

Australia's universities and research agencies provide a launch pad. If investment in PPPs is scaled up sufficiently and the net is cast wide enough to draw in key partners from American, European and other 'friendly' geopolitical shores, then a network of R&D and industry actors could forge an Australian entry into the global semiconductor ecosystem—a key investment in the nation's digital future.

With a focus on compound semiconductors, across the span of Australian universities and at CSIRO (the public research sector) there's extensive research-scale design and fabrication capability distributed across Australian states and territories.

Specifically, under the National Collaborative Research Infrastructure Strategy (NCRIS),[15] the Australian National Fabrication Facility (ANFF)[16] was founded in 2007 to provide access to micro- and nanofabrication equipment, which is essential to Australia's scientific future. Enabled by the NCRIS, the ANFF has become a cornerstone of semiconductor-based research in Australia and now represents an investment of more than A$400 million in research infrastructure made by federal and state governments and partner organisations.

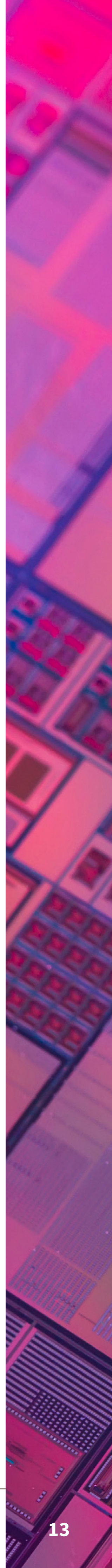
More specifically, the ANFF distributed network spans fabrication facilities across eight nodes and 18 Australian universities (see box). Compound semiconductor and photonics fabrication capability form a centre of gravity in that span.

ANFF network: Launch pad for Australian commercial fabrication capacity via PPPs

NSW node:	University of NSW, University of Sydney
Victorian node:	University of Melbourne, Monash University, Deakin University, La Trobe University, Swinburne University of Technology, RMIT, CSIRO
Queensland node:	University of Queensland, Griffith University
South Australian node:	University of South Australia, Flinders University
Western Australian node:	University of Western Australia
ACT node:	Australian National University
Materials node:	University of Wollongong, University of Newcastle
Opto-fab node:	Macquarie University, University of Technology Sydney, University of Adelaide, University of Sydney

While public-sector fabrication research prioritises innovation over the volumes and yields required for commercial operation, partnerships between Australia's university research network and commercial prototyping design and fabrication entities open a way forward.

Two examples of successful partnerships between a semiconductor company and Australian universities in the ANFF network are as follows:



- **Silanna Group and the University of Adelaide**

  The Silanna Group was founded in 2006 and is cited as Australia's only semiconductor design and manufacturing company.[17] With its head office in Brisbane and additional operational, manufacturing and design centres in Sydney, the US, the UK and Singapore, Silanna supplies high-technology microelectronic chips to the global communications, space, defence and medical markets.

  The picoFAB facility, collaboratively designed by Silanna and the University of Adelaide, supports Silanna's advanced compound semiconductor research program employing molecular beam epitaxy across three deposition chambers, each designed to grow composite materials at the quantum scale. The University of Adelaide–based partnership provides a direct R&D innovation and talent pipeline to a co-located and more strictly controlled commercial operation.

- **Microsoft Station-Q and the University of Sydney**

  Microsoft Station-Q Sydney is a strategic partnership forged between Microsoft and the University of Sydney in the field of quantum computing and the emerging quantum economy, fostering skills, strengthening research and forging critical industrial connections, and has a strong semiconductor electronics focus.[18] This Australian arm of Microsoft's global Station-Q forms a key part of its initiative to create a useful, scalable general-purpose topological quantum computer.

  The Sydney Station-Q team is one of only four experimental Station-Q teams worldwide, alongside teams at Purdue University, Delft University of Technology and the University of Copenhagen. Of note in the context of Australian semiconductor capability, Station-Q Sydney is co-located with the University of Sydney's A$150 million Nanoscience Hub for Semiconductor Fabrication.

Both Silanna and Microsoft Station-Q Sydney, while co-located and connected with their university partners, are suitably 'air-gapped' from the university research facilities in relation to the more stringent, high-volume requirements of their commercial operations and markets. As a model, this is highly suited to the Australian semiconductor 'foothold' and offers a base to build on. Further, building commercial semiconductor fabrication capacity on the ANFF R&D footprint distributed across Australian states and territories offers the potential for a distributed model of several foundries targeting a span of specific markets that, in addition to federal incentives, could garner considerable leverage from multiple state governments.

US and UK reference points

Notable developments in the US and the UK underscore both the escalating importance of compound semiconductor markets and the concept of semiconductor industry scale-up via PPPs centred on advanced university-based R&D fabrication facilities and stimulated by government incentives. We set out four examples below.

US: University of California

A tangible example of growth potential in important technical areas offered by the compound semiconductor sector involves recent progress at the University of California Santa Barbara[19] and in Australian universities in the field of semiconductor chip-based laser technology for fully integrated photonic systems. In this specific example, indium phosphide distributed feedback semiconductor lasers and aluminium-gallium-arsenide-on-insulator micro-resonators are combined with a variety of silicon-on-insulator photonic circuits for important applications, paving the way for large-volume, low-cost manufacturing of chip-based next-generation high-capacity transceivers, data centres and space and mobile platforms.

UK: Arm Holdings

Important guidance relevant to Australia is provided by recent initiatives in the UK. For silicon CMOS, the UK no longer manufactures silicon chips due to the escalating cost of silicon fabrication plants, opting instead for offshore fabrication, and has focused on the fabless design of microprocessors and a licensing model.

This focus on pushing the innovation and commercial barriers on fabless design has been exemplified by Arm Holdings, which is a world-class Cambridge-based semiconductor and software design company known for its design of CPUs, system-on-platform and system-on-a-chip infrastructure and software. Arm's importance as a British national security and economic asset became clear in 2021, when the British technical establishment, the government and defence sector lobbied hard to block the acquisition of Arm (owned by the Japanese company Softbank) by the American semiconductor firm NVIDIA.

The deal was eventually blocked by the US Federal Trade Commission on anti-trust grounds in 2022,[20] but it showed the importance of proactive UK Government–driven technology policies that can effectively ring-fence strategic sectors such as semiconductors.

Arm's deep ties to Britain's university-based researchers and the world's top talent ecosystem in chip design highlight the importance of PPPs in the semiconductor sector.

UK: Catapult program

The UK has, however, targeted compound semiconductor (CS) fabrication, as exemplified by its £50 million Catapult program,[21] which is aimed at establishing the UK as a primary global research and manufacturing hub for CS technologies and positioning UK tech companies ahead of the curve with investments in R&D and fabrication infrastructure for next-generation electronics.

Catapult has focused on selected markets that exploit three technical advantages of CSs:

1. *speed*—to operate at higher frequencies compared to silicon for high-speed data transfer over 5G networks
2. *light*—to both emit and detect light efficiently for sensors relevant to the health sector and photonics more generally
3. *power*—to handle higher power levels than silicon, which is relevant for example to electric vehicles and more generally to power electronics.

While the dominant global silicon market is worth some US$300 billion, the CS market is worth a substantial US$74 billion and has a significant forecast growth rate, of which the UK has captured a 10% share.[22] Importantly, the UK's CS strategy builds on investments of more than £750 million over the past decade by its Engineering and Physical Sciences Research Council and Innovate UK (which are both part of United Kingdom Research and Innovation) in research-scale facilities that prioritise innovation.

This somewhat mirrors the NCRIS-enabled ANFF investment in Australia, which could similarly act as a base underpinning a national semiconductor strategy. Funding for the UK Catapult program exceeds the Australian ANFF's funding, which is purely for infrastructure, as it also provides funding for both targeted R&D staff and facilitators in the private and public sectors.

In addition to emulating Arm-like ecosystems locally, Australian universities, publicly funded research entities and private firms should look further afield and become enmeshed in the innovation ecosystem of an Arm.

US: Purdue University, SkyWater and US Government

Purdue University in Indiana is the site of a US$1.8 billion investment by US semiconductor manufacturer SkyWater Technology Inc., where it's building a chip research and production facility.[23] SkyWater's 90 nm and 130 nm silicon CMOS processes represent the top of their product range. That mature process scale, however, keeps the cost of the fabrication plant down (a modest US$1.8 billion price tag versus a US$10–20 billion investment for a leading-edge foundry making 7 nm or 5 nm chips) and is ideally suited for a university–industry partnership in producing commercial-grade chips.

This is an important development for two reasons. First, the SkyWater Technology investment at Purdue University has been cognisant of the then upcoming CHIPS Act, which provides some US$52 billion in US Government subsidies for semiconductor research and fabrication capacity in the US. A further US$24 billion in tax incentives is provided by the related Facilitating American-Built Semiconductors (FABS) Act.[24]

The second reason why the link-up between Purdue University and SkyWater is important is that it underscores the importance of having national production capacity in the so-called 'trailing-edge' or 'mature' range of the semiconductor spectrum. While most of the attention in semiconductor GVCs has been on the 'leading-edge' portion of the spectrum (7 nm – 2 nm CMOS, which are true technological marvels with huge realpolitik implications), trailing-edge chips are critically important for economic and national security. Older generation chip technology is in high demand for a range of defence applications, cars, medical devices, logistics, agri-tech, clean-tech and everyday consumer products. For newcomer producers, barriers to entry are lower and yet the economic benefits of capturing market share in this space are significant.

US CHIPS and FABS Acts and developments in China

The US CHIPS and Science Act (passed in July 2022) is a countermeasure to China's massive spending initiatives on strategic technology development, which from 2020 to 2025 will invest US$1.4 trillion in technological development and capacity building.[25] This US Act and the related FABS Act, therefore, provide a further US$170 billion for R&D and production of, for example, 5G and 6G wireless technology, AI and quantum computing in addition to focusing on semiconductor value chains (see box).

US Government CHIPS and FABS Acts for the semiconductor industry

CHIPS Act: Creating Helpful Incentives to Produce Semiconductors and Science Act

- US$52 billion in federal incentives to promote semiconductor manufacturing and increased investments in semiconductor research.

FABS Act: Facilitating American-Built Semiconductors Act

- US$24 billion tax credit for investments in constructing, expanding and upgrading semiconductor manufacturing facilities and equipment in the US, and a credit for semiconductor design.

Grants and tax credits for chip manufacturing and design reinforce each other:

- Grants offer targeted, one-time incentives for manufacturing (construction of foundries).
- Tax credits (four-year, 25% credit) for manufacturing and design offer predictable incentives to continue ongoing investments to construct, upgrade (equipment), and expand new and existing facilities and to conduct advanced chip design.

The CHIPS Act also includes investments in advanced development, such as funding for the National Semiconductor Technology Center and the Advanced Packaging Manufacturing Program:

- Investments in semiconductor research will help to ensure that the US remains the global technology leader and will help to educate the next generation of innovators, thereby providing the pipeline of scientists and engineers needed for the US economy and national security.
- Funding facilities for advanced prototyping and piloting will help inventors through the 'valley of death' where innovative ideas funded as pre-competitive basic research are unable to secure the necessary investment to become commercially viable.

Sources: 'Enact bipartisan competitiveness legislation to strengthen semiconductor research, design, and manufacturing in the US', *Semiconductors*, 2022, online; 'Congress passes investments in domestic semiconductor manufacturing, research & design', *Semiconductors*, 2022, online.

China, which still lags far behind the US, Taiwan, South Korea and Japan in the leading-edge chips race (particularly as sanctions and export controls have further stymied Beijing's ambitions), is on the verge of surging ahead in trailing-edge semiconductor production.

China is slated to build 31 major semiconductor fabrication plants by end of 2024, which exceeds the 19 coming online in Taiwan in the same period and the 12 expected in the US.[26]

Beijing's large-scale investment in the trailing-edge market segment, which includes microcontrollers that perform myriad functions, particularly for power-supply chips widely used in cars, phones and electronics, shows that it fully understands the strategic benefits of dominating this market segment. The consulting firm International Business Technologies estimates that by 2025 China will transition from producing 15% of the world's 28 nm-node chip capacity, to 40%.[27] Therefore, the US and its key allies must focus on expanding production of trailing-edge semiconductors, not just look to increasing their primacy in the leading-edge race.

In purely cost terms, it's in the trailing-edge range that companies with important end-market linkages might potentially invest in Australia with appropriate government incentives such as those set out in the US CHIPS and FABS Acts.

The Purdue announcement, therefore, is very relevant to the Australian situation. Incentivising a distribution of commercial fabrication plants nucleating around NCRIS ANFF nodes, via PPP initiatives with a CMOS basic chip focus, also makes sense.

Defence-related technology transfer

While PPPs involving trusted leading-edge universities, governments and firms are vital to Australia's semiconductor plans, there's one other critical component that must be tapped: technology transfer via defence initiatives.

These security-focused technology initiatives are limited to just a small handful of trusted allies that share core values and close historical and cultural ties with Australia. That narrows the choice down to, primarily, the US and the UK.

AUKUS, the Five Eyes and the Quadrilateral Security Dialogue

For this reason, the AUKUS trilateral security pact involving Australia, the UK and the US, in which Australia is set to receive eight conventionally armed nuclear-powered submarines, is a primer for Australia's semiconductor strategy. AUKUS confirms that leading-edge defence-related technology transfer is occurring not just across the North Atlantic, but has now moved to the South Pacific.

The development and production of semiconductors and other related technologies needed for navigation and surveillance, advanced communications and weapons systems in defence platforms mean that AUKUS could transform Australia's technical landscape.

In the same vein, Australia's participation in the Five-Eyes alliance has an intelligence-sharing focus, with the US, the UK, Canada and New Zealand. With that focus, its success is coupled to national prowess in semiconductor value chains, from R&D and fabless innovation to fabrication.[28]

Similarly, Australia's membership in the Quad with the US, Japan and India offers potential friend-shoring opportunities for certain kinds of technology transfer and GVC ring-fencing. The Quad presents a somewhat less well-defined framework for diplomatic and military cooperation to keep the Indo-Pacific free and open—a clear response to China's growing economic and military activities in the region.

India, with its long history of non-alignment, and its reliance on Russia for its energy and arms-related needs, complicates things from a long-term trust and reliability perspective for Australia. Nonetheless, New Delhi's growing geopolitical enmity with Beijing, and its efforts to decouple economically from Chinese supply chains, present various security cooperation (and open market) opportunities for Australian firms in the mature trailing-edge band of semiconductor GVCs.

Japan's growing strategic importance as a Quad partner, and recent policy changes within that framework, make Tokyo an increasingly valuable partner for Australian PPPs in both trailing-edge and leading-edge semiconductor technologies.

The role of US DARPA, the Australian Strategic Research Agency and UK Advanced Research and Invention Agency

In the US, the Defense Advanced Research Projects Agency (DARPA) has been instrumental in bringing together research institutions, industry and the defence establishment around high-priority security technologies. DARPA, which has a published 2023 budget of US$4.1 billion, has been active in PPPs involving semiconductors.[29]

Beyond the significant role played by important existing Defence Science and Technology Group programs, including through the Technical Cooperation Program with its Five-Eyes counterparts, and CSIRO initiatives in engaging industry and university sectors to form strategic partnerships in key technology areas, the Australian Government has announced its intent to stand up a new agency: the Australian Strategic Research Agency (ASRA).[30] ASRA is intended to link Australia to key allies through PPPs engaged in pivotal research in breakthrough technologies for national security.

ASRA has the potential to boost Australia's involvement in technology sharing and R&D through the new AUKUS partnership, working closely with US DARPA and the newly created UK Advanced Research and Invention Agency. This trilateral relationship, with its joint emphasis on urgency, will be an important asset in defining and executing Australia's national semiconductor plan.

Government stimulus of public–private partnerships: with what focus and scale?

The Australian Government, through DISR's A$1.3 billion Modern Manufacturing Initiative (MMI),[31] is co-investing with industry in manufacturing, resources technology and critical minerals processing; food and beverages; medical products; recycling and clean energy; defence; and space. The MMI aims to help Australian manufacturers scale up, collaborate and commercialise. Of note, the semiconductor sector isn't specifically identified, although its microchips heavily underpin all of those priority areas. We also note that, post-election, the MMI grant program is under review by the new government. The National Reconstruction Fund is the current government's flagship industry initiative.[32]

As set out above, the US Government, through its CHIPS and FABS Acts, is acting decisively to stimulate its semiconductor sector via US$52 billion in subsidies for additional fabrication capacity and US$24 billion in tax concessions for equipment within new and existing fabrication facilities, plus increased semiconductor design capacity. Of note, attracting investment in semiconductor chip capacity on US soil via offshore companies relocating and diversifying their operations is encouraged (such as a planned TSMC chip wafer factory in Texas).

As identified by the NSW CSE semiconductor report, while Australia has a small commercial semiconductor ecosystem, its commercial chip fabrication capacity is all but absent. While some would argue that because of this low base commercial fabrication isn't the place to start, we advocate quite the opposite. Unless Australia makes a start here and addresses this centre of gravity, we'll forever be a bit player and reliant on foreign supply chains. It's all too easy to send this issue off down a design-alone pathway. In a rules-based, ordered world that might be acceptable. In the real world, and in the face of supply-chain uncertainty, it is not.

We caveat this focus with the comment, however, that consideration should also be given to the entire semiconductor supply chain beyond fabrication (the whole 'tech-stack'), to reinforce Australia's strengths where they exist and the potential to enhance its role in the supply of critical minerals, and its design capability in, for example, specialised areas of photonic and 5G/6G system chips.

With that caveat, the question then is: in what manner and at what scale can commercial fabrication capacity be stimulated in Australia? International comparisons are helpful here.

The UK has focused on more affordable compound semiconductor fabrication leveraged on its R&D strength and has captured 10% of the world market. This market area is escalating, and Australia could similarly weigh in, particularly in photonic chip markets.

The US has provided government stimulus measures that Australia could scale and emulate. While scaling up Australian companies is important, starting from a point of their near-absence in fabrication means that public–private joint ventures with offshore firms to establish fabrication capacity on Australian soil will be central to growing the ecosystem.

In framing what an Australian moonshot might target, and broadly its dollar scale, we advance the following scenario. This isn't meant to be prescriptive but makes tangible what a 'start' might comprise.

Australia has invested A$0.4 billion in its ANFF R&D network. It could arguably invest such an amount again in ANFF to scale up the current capability to pilot production in key nodes and areas of demonstrated innovation geared to escalating markets. An initial goal could then be to leverage off that upscaled, more commercially focused ANFF capability to then stimulate PPPs with semiconductor firms around two key ANFF nodes: one in composite semiconductor fabrication and a second foundry in mature-process-scale silicon CMOS similar to the US$1.8 billion Purdue University – SkyWater initiative.

Each of those commercial fabrication facilities would be broadly of the order of A$2.0 billion investments. Adding in support for semiconductor design, this would represent close to A$5 billion of activity: two times A$2 billion for the commercial plants, the existing A$0.4 billion that ANFF represents plus that amount again for upscaling, and a similar provision of A$0.4 billion to boost an aligned sovereign design capability.

Government stimulus measures, emulating US semiconductor Acts that provide direct subsidies and tax concessions, at say a 30% investment level, plus the bulk of the ANFF and design reinforcement cost, would be of the order of A$1.5 billion within the A$5 billion total from all parties. This is on par with the total government investment in Australia's MMI across all priority areas. Given that semiconductors are integral to the full span of the MMI, this approach could also be thought of as doubling the government MMI investment to secure Australia's underpinning of its semiconductor base in the medium term.

In the longer term, and with such a base, attracting investments from leading-edge semiconductor fabrication firms in Australia shouldn't be excluded from government consideration.

Strategic recommendations

This study has laid out the problem of Australia's over-reliance on foreign-made semiconductors and its current lack of participation in semiconductor GVCs. To offer important elements of a solution to this problem, we've provided an analysis of Australia's existing semiconductor landscape, also drawing on other studies, and have focused on specific areas of promise that form a foundation upon which to build Australia's national semiconductor strategy. We've also drawn attention to the centrality of achieving a strong, targeted Australian commercial semiconductor fabrication capacity in this calculus, building on an existing public-sector R&D foothold.

In summary, and erring on the side of sharp, specific recommendations, the following key elements are proposed for consideration to progress the formulation of Australia's national semiconductor plan through the office of Australia's Chief Scientist and by DISR:

1. In the medium term, via a PPP mechanism, prioritise and stimulate the establishment of a distributed commercial compound semiconductor foundry capability across Australian states and territories through federal and state government incentives and private sector co-investments driving strategic commercial partnerships with reinforced NCRIS ANFF R&D nodes.
2. Such Australian government incentives could proportionately emulate subsidies and tax concessions set out in the US CHIPS and FABS Acts.
3. In the longer term, similarly incentivise the establishment of a commercial silicon CMOS foundry at mature process scale, as exemplified by the US Purdue University – SkyWater initiative facilitated by the US CHIPS Act measures.
4. Reinforce investment in the ANFF R&D network itself to firm up the sustainability of this national foundational building block, to future proof its staffing and R&D facilities, and to drive the additional development of innovative, translational pilot production infrastructure bridging research and commercial manufacturing operations. Similarly reinforce an aligned sovereign design capability.
5. The combined scale and span of this distributed fabrication capability should aim to ensure a strategic supply of trusted high-technology microelectronic chips to the communications, space, defence and medical markets across Australia and alliance/partner nations, connecting to their combined fabless compound semiconductor and silicon design strengths and servicing their semiconductor-reliant business ecosystems.

6. Ensure that a local talent and innovation pipeline reinforces such an Australian-based commercial foundry network via formal training arrangements with the research-scale compound semiconductor and silicon fabrication capability across Australian universities and government research and development agencies, and via semiconductor-oriented degree and technical qualifications from universities and TAFE colleges.
7. The strength of the talent pipeline would be increased and optimised by a formal collaboration framework on semiconductor research and training among key research universities across alliance nations, mirroring government agency arrangements (such as the Technical Cooperation Program for defence R&D of Five-Eyes nations).
8. Examine the UK's Catapult program for compound semiconductor fabrication and public–private investment in a compound semiconductor cluster in South Wales focused on speed (RF and microwave technologies), light (photonics and sensors) and power (power electronics), connecting research organisations and business, as a useful benchmark.
9. Similarly, technical guidance in establishing state-of-the-art trusted compound semiconductor foundries in Australia would benefit via a cooperative R&D agreement between government laboratories, such as between the US Department of Energy's Sandia National Laboratory, which hosts both national compound semiconductor and silicon CMOS facilities and expertise, and CSIRO.
10. Position Australian semiconductor capability in an alliance (Five Eyes, AUKUS, Quad) and partner nation secure supply-chain context, in a market that builds on its innovation strength, via fabrication capability that it can both afford and support and for which it has a small but experienced research base.

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Acronyms and abbreviations

AI	artificial intelligence
ANFF	Australian National Fabrication Facility
ASRA	Australian Strategic Research Agency
CHIPS Act	Creating Helpful Incentives to Produce Semiconductors and Science Act (US)
CMOS	complementary metal-oxide semiconductor
CPU	central processing unit
CS	compound semiconductor
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DARPA	Defense Advanced Research Projects Agency (US)
DISR	Department of Industry, Science and Resources
EU	European Union
FABS Act	Facilitating American-Built Semiconductors Act (US)
GVC	global value chain
IP	intellectual property
MMI	Modern Manufacturing Initiative
NCRIS	National Collaborative Research Infrastructure Strategy
nm	nanometre
NSW CSE	NSW Government Chief Scientist and Engineer
PPP	public–private partnership
Quad	Quadrilateral Security Dialogue
R&D	research and development
RF	radiofrequency
SCRI	Supply Chain Resilience Initiative
TSMC	Taiwan Semiconductor Manufacturing Company

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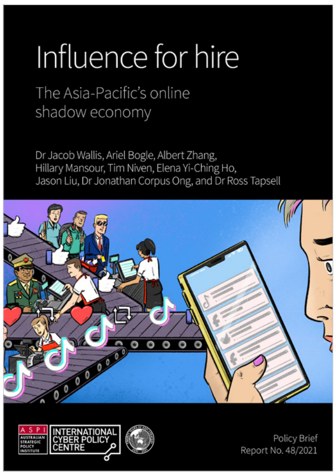

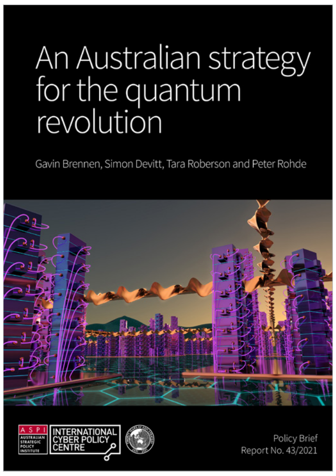

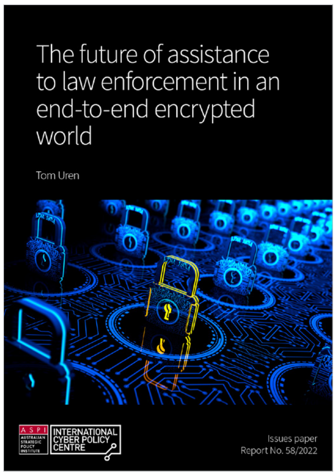

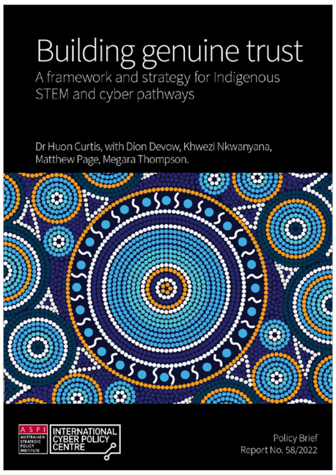

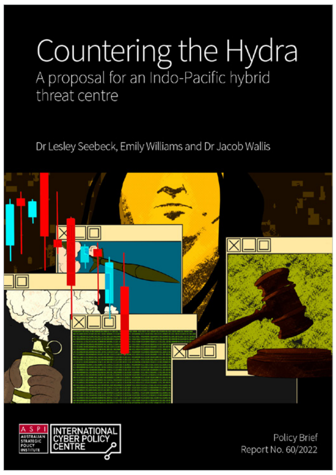

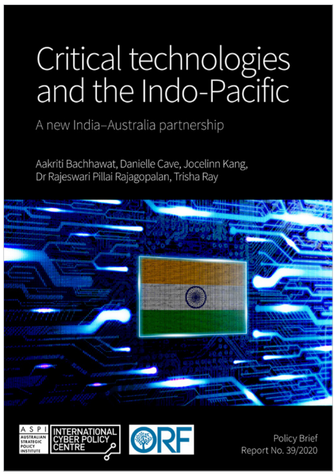

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