Australian Semiconductor Sector study

Capabilities, opportunities and challenges for increasing NSW's participation in the global semiconductor value chain

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This report has been prepared for the Office of the NSW Chief Scientist & Engineer by the University of Sydney Nano Institute

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Foreword

The Sydney Nano Institute undertook this scoping study on behalf of the Office of the NSW Chief Scientist & Engineer. Our aim was to provide an independent, industry-focused perspective on the current state and demand for semiconductor capability in Australia, and to suggest opportunities for future growth. Semiconductors are the key component in the most advanced electronic systems and will underpin development of emerging technologies for a long time to come. We would like to thank the more than 100 individuals, companies and government agencies who participated in interviews and discussions that contributed to the development of this report, and the Maltby Group, who were instrumental in delivering the study.

We are approaching the end of 2020, a year which has challenged our thinking and forced changes in the way we work, research and collaborate. While this scoping study was initiated prior to the emergence of the current global health crisis, the events of 2020 have only intensified our focus on things such as sovereign capability, supply chain security, productivity, value-adding and value-capture, where manufacturing and high-tech are at the top of the list.

This report should not be regarded as an endpoint. This is where we start.

The study has taken into consideration all facets of the global semiconductor value chain, and how we might fit into it more meaningfully; leveraging those areas that we have strengths and anticipating areas of emerging need. A key takeaway is simple: small steps aligned with a long-term vision for the Australian semiconductor industry will create new capability, talent pools, businesses and new options that all may make significant impacts on a 10- or 15-year horizon. There are many and varied global examples that we can draw from to help define and build a unique and valuable capability. Ultimately, with long-term and deep commitment, success in semiconductor research and translation will lead to increased knowledge, jobs, prosperity and security for NSW and Australia.

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EXECUTIVE SUMMARY

The semiconductor sector is a global engine for technology, economic and social progress within high participant countries. The semiconductor global value chain is among the most complex, capital intensive, extended and dynamic of any industry. It is intrinsically linked to the performance of high technology, which drives much of our digitally dominated present and future. Increasingly the sector is also seen as an important theatre of national and international security concern.

Australia's semiconductor sector is relatively small compared to some other economies, but Australia is not without areas of strength and strategic significance. With a long-term view and commitment, there is potential for NSW and Australia to increase their participation in the global semiconductor value chain. The very dynamism and change which has characterised the last 40 years of the semiconductor industry – and allowed countries such as Taiwan and Singapore to emerge and prosper – will only increase over the next 40 years. This presents an opportunity for new participants, such as Australian firms with new products, processes or business models, to enter and prosper in the global semiconductor value chain and related industries.

Recognising this potential opportunity, the Office of the NSW Chief Scientist & Engineer (NSW OCSE), in conjunction with the Sydney Nano Institute, undertook this Australian semiconductor sector scoping exercise to map capabilities and identify challenges and opportunities in the sector. This study's objective is to assess if, where and how NSW and Australia might more meaningfully participate in the global semiconductor value chain. The study considers findings from extensive secondary research and over 100 consultations with Australian and international participants across the full semiconductor value chain.

The analysis of challenges looked at the root causes for Australia's present low relative standing within the global semiconductor sector. International case studies were examined to identify policy options and alternatives. The consultations and secondary research revealed underlying themes, or 'levers', around which actionable initiatives could be developed to address these challenges, leverage existing capabilities and take advantage of near- and long-term opportunities. There is a wide range of potential initiatives, each with their own benefits, costs, risks and implementation nuances relevant for the Australian context. An overall finding of this study is that Australia needs to: match emerging market opportunities that are suited to Australia's strengths; and make 'step-wise' commitments to investment, capability building and coordinated, competitive strategies for value creation and capture.

Australia has historically demonstrated an impressive appetite to adopt technological innovation. Generally, we are among the first countries to onboard new technologies. There are immense benefits from early and rapid technology adoption, including benefits to productivity and Australia's relative value-added capacity in industry. Arguably though, this is relegating Australia to only a decent second prize. There are even more potential benefits in our own encouraged, created and delivered technology. To generate and capture these benefits, on the back of innovative, IP-backed products and services, is to compete for first prize.

Today, Australia's semiconductor sector is relatively small compared to some other economies, but as this OCSE study into the semiconductor sector revealed, Australia is not without areas of strength and strategic significance across the semiconductor value chain and in specific markets. With a long-term view and commitment, there is potential for the increased participation of both NSW and Australia in the global semiconductor value chain and the benefits of jobs, prosperity and security this brings.

Contents

Tables

Figures

1 THE GLOBAL SEMICONDUCTOR SECTOR VALUE CHAIN

1.1 WHAT ARE SEMICONDUCTORS?

Semiconductors, often referred to as 'chips', are the electronic 'engines' underlying almost all technology applications, and hence a significant proportion of regional, national and global industry development, economic performance and growth. Chips perform all the calculations in computers (digital logic), industrial control systems in manufacturing, traffic control systems, medical devices, aircraft, to name but a few applications and markets. Other kinds of chips store data, as memory, in computers, servers and data centres. Still other types of chips create and receive radiofrequencies (RF) as the backbone of all wireless communication systems.

The rapid pace of change and reliance on semiconductor chips is illustrated by their use in automobiles: chips did not first appear in commercial vehicles until 1968, but today there are over 50 chips in the average car. Chips and the related electronics now account for about 40 per cent of the total cost of an average car.[1,2] Electric and autonomous vehicles will likely increase the proliferation and reliance on chips even further.

Being vital to most defence, space and critical infrastructure systems and applications, capabilities related to chip design, fabrication and intellectual property protection are also of high strategic significance. As one of the most complex products to develop (over 400 separate process steps) semiconductors represent both a key industry and enabler for other industries. As a result, the sector assumes an even greater level of economic, social and strategic importance.[3]

Chips come in many types and are applied in diverse end-use markets, each market with its own set of performance and cost requirements, and market dynamics. The main distinct 'families' of semiconductors, each with their own market dynamics, are: memory; logic; microprocessors; analog; opto-electronic; sensing; and discretes. The functionality incorporated into chips, either in pre-fabrication design or post-fabrication programming, are diverse. Post-fabrication programming allows a chip to be used for many possible applications. These applications are as varied as landing a rocket on Mars, changing traffic lights, running a washing machine, tracking a heartbeat and Global Positioning System (GPS) position, running Machine Learning (ML) and Artificial Intelligence (AI) algorithms, or driving the sensors and connectivity in Internet of Things (IoT) devices and networks.

1.2 SEMICONDUCTORS AS A CRITICAL INTERMEDIATE GOOD

Semiconductor chips are a critical intermediate good in a vast value chain, which then feeds into multiple industry value chains. The semiconductor sector includes an important set of markets such as: markets in materials (for example, high-grade silicon); capital equipment for manufacturing (where tens to hundreds of specialised pieces of equipment each costing up to US$150M are utilised within a single chip fabrication plant); chip design and architecture, including the use of Intellectual Property (IP) Blocks such as those offered by Arm (a British semiconductor company dominant in mobile phones and tablets); as well as fabrication, test and packaging. Most people conceive of the semiconductor sector as solely focused around 'branded chips' from companies such as Intel, AMD or NVIDIA. Gaining

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[1] Deloitte, 2019, *Semiconductors - the next wave. Opportunities and winning strategies for semiconductor companies*.
[2] KPMG, 2019, *Automotive semiconductors: the new ICE AGE*.
[3] For example, see the detailed semiconductor sector analysis, conducted from a US perspective by the Semiconductor Industry Association. Semiconductor Industry Association, 2016, *Beyond Borders: The Global Semiconductor Value Chain.* Semiconductor Industry Association, 2020, *SIA Fact Book, 2020*.

more attention lately due to supply-chain and geopolitical concerns are the 'pure-play' semiconductor fabrication companies, such as Taiwan Semiconductor Manufacturing Company (TSMC). However, the semiconductor value chain extends downstream with more economic profile than it does upstream. Industries affected by the dynamics of the semiconductor sector range from the consumer to industrial, from telecommunications to defence, from transport to medical. Not only is the semiconductor value chain vast in its breadth and multi-market complexity, but it is of large direct and indirect economic consequence.

The global semiconductor market for just the chips themselves is around US$425 billion per year today and by some estimates is forecast to hit US$1 trillion by 2030.[4] However, as an intermediate good, chips are used downstream in a huge variety of equipment and devices – for example, in smartphones, cars, and medical devices. The equipment market incorporating chips is, by some estimates, at least US$4 trillion per annum.[5]

Just as importantly, the chip itself is the result of an elaborate up-stream value chain starting from inputs such as minerals in the ground, through mining, refining and processing into silicon wafers (often 'doped' with rare and critical earth minerals), then fabricated into chips that have been designed with, and utilising, sophisticated tools and engineering expertise. The chip fabrication process is one of the most complex sets of processes for any manufactured good on the planet. Scale, hence large capital expenditures, and high levels of research and development to sustain competitive differentiation, are characteristic of many steps in the semiconductor value chain.

These economic and structural fundamentals have resulted in a fracturing of business models across the value chain over time. Previously the path to market was to design, manufacture and sell the chips all within the one company, the so-called Integrated Device Manufacturer (IDM) approach still largely exemplified by Intel. The currently ascendant business model duality is for pure-play manufacturers (for example, TSMC) to provide fabrication services to the many hundreds of 'fabless' chip companies (for example, AMD, NVIDIA and Qualcomm) who focus primarily on the design and marketing of chips. Further evolution of the value chain should be expected as competition drives both incremental as well as discontinuous R&D, new market opportunities open up (such as ML, AI and IoT), and new business models are ventured. While 'adopters' of technology resulting from this vast value chain, such as Australia, have benefited as much as any other country, it is countries such as Singapore, Taiwan, and China that have seen their absolute and relative prosperity soar as they embraced opportunities across the semiconductor value chain. Figure 1 illustrates the semiconductor value chain.

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[4] Oxford Economics, 2013, *Enabling the Hyperconnected Age: The role of semiconductors*, www.semismatter.com/enabling-the-hyperconnected-age-the-role-of-semiconductors. Semiconductor Industry Association, 2020, *2020 SIA Fact Book.* Semicon West Conference (Virtual) 2020, presentation by Ajit Manocha, July 2020.
[5] British Broadcasting Corporation, 2020, *The humble mineral that transformed the world,* accessed November 2020, https://www.bbc.com/future/bespoke/made-on-earth/how-the-chip-changed-everything.

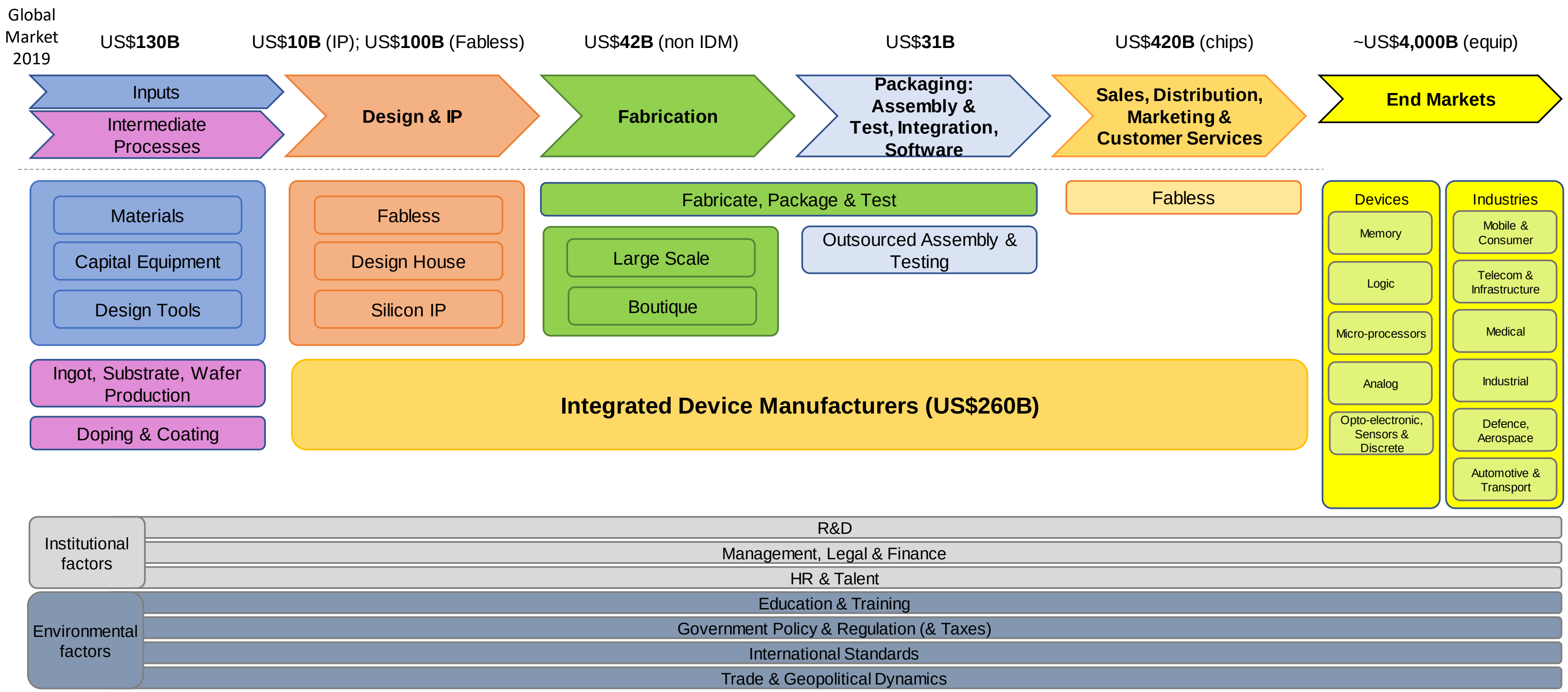

Figure 1: Semiconductor value chain

Note: Global market size estimates in US$ billion. Refer to Appendix 2 for references supporting estimates of market size in 2019.

1.3 SEMICONDUCTORS AND NATIONAL PROSPERITY

The semiconductor sector continues to be a global engine for technology, economic and social progress. Countries with long-term participation in the semiconductor sector, such as the US and Japan, have enjoyed corresponding levels of economic prosperity. Countries such as Singapore, Taiwan, China, South Korea and Israel have implemented deliberate national industrial policy strategies and initiatives to not only participate in the semiconductor value chain but to rise in prominence and significance. These comprehensive national-based policies have leveraged and accelerated existing and emerging comparative and competitive advantages held by each country. A third group of countries, represented by Ireland and to a lesser extent Malaysia, Vietnam, India and the Philippines, have more recently created a presence in the semiconductor sector, utilising different value chain insertion approaches.[6] A historically fragmented European Union (EU) market now appears to be gathering a more coordinated and unified set of initiatives.[7]

Meanwhile, Australia's participation in the semiconductor sector has progressed in fits and starts. In the 1950s, Australia was actively involved in the semiconductor sector via government agency-sponsored individual level technology transfer arrangements with US R&D organisations which then became the basis for domestic research, development and manufacturing capability enhancement. This led to some successes, such as Wi-Fi[8] and chips for the Mars Rover in the early 2000s[9]. However, today Australia is much more a 'consumer' of semiconductor products rather than a value-added participant in the development of semiconductors. In general, Australia now finds itself lagging in semiconductor value creation, delivery and capture, and lacking strategic supply-chains and security profiles in one of the world's most technologically significant and challenging sectors.

1.3.1 Semiconductors and economic complexity

There is a growing view that an economy's 'complexity' has a considerable influence on its relative economic positioning, performance and hence its current and future prosperity. At least one measure of complexity, the Economic Complexity Index (ECI), has Australia's multi-decade complexity ranking dropping precipitously, while economies with considerably more semiconductor sector participation (along with other diversified, technologically advanced economic activities) have demonstrated both sustained and in many cases increasing performance (Table 1).[10]

[6] A useful general introduction to global value chain analysis, insertion and upgrading options is presented in Gereffi and Fernandez-Stark, 2016, *Global Value Chain Analysis: A Primer*.

[7] Individual national efforts (and differences) within the EU have provided isolated successes, a number of which continue to reap benefits today for their individual countries and regions.

[8] A history of the commercial development of the first Wi-Fi chips by Radiata, and some antecedent research programs which assisted Radiata's technical development, is provided in Matthews and Frater, 2003, *Creating and Exploiting Intangible Networks: How Radiata was able to improve its odds in the risky process of innovating*.

[9] These chips were manufactured in western Sydney at the then named Peregrine Semiconductor Australia facility in 2004. Walker, F. 2008, 'How Germany closed its coal industry without sacking a single miner', The Sydney Morning Herald, 13 January 2008, accessed November 2020, https://www.smh.com.au/national/our-chips-firing-mars-rovers-20080113-gdrwmw.html.

[10] From Harvard University's *Atlas of Economic Complexity*: "Economic development requires the accumulation of productive knowledge and its use in both *more* and *more complex* industries. Harvard Growth Lab's Country Rankings assess the current state of a country's productive knowledge, through the Economic Complexity Index (ECI). Countries improve their ECI by increasing the number and complexity of the products they successfully export."

Table 1: International comparators, economic complexity and semiconductor sector participation

Country	ECI Ranking		Semiconductor sector participation
	1995	2018	
Japan	1	1	Japan has been a semiconductor powerhouse across the whole value chain since its first establishment there in 1965. While Japan has recently experienced noticeable losses in global market share in fabrication and equipment, it still leads in many areas of semiconductor sector materials, process engineering, integration, and end-product design.
South Korea	21	3	South Korea has seen its share of worldwide semiconductor sales increase from about 6 per cent in the early 1990s to 17 percent in 2014.
The United States	9	11	The United States' semiconductor global market share has remained roughly steady at around 50 per cent for the past 20 years, yet the industry's contribution to the US economy, as measured by growth in real value added, has accelerated amid globalisation, increasing 265 per cent from 1987-2011. The pace exceeded that of any other manufacturing industry in the US. Value added jumped to US$65 billion per year from US$50.3 billion during 2007-2011, growing far faster than GDP as a whole. Among manufacturing industries, only petroleum refineries and pharmaceutical preparation makers contributed more to US GDP in 2007 and 2011.
Ireland	16	17	Intel has invested over US$15 billion in its Ireland operations since 1989, claiming US$1 billion in benefit to the Irish economy each year, a direct workforce of over 5,000 and total jobs supported of over 6,800.
China[11]	46	18	China has increased its share of worldwide semiconductor sales from almost zero in the early 2000s to 4 per cent in 2014.
Israel	19	20	From zero in 1974, Israel now has over 150 semiconductor companies. Intel alone employs 12,800 staff and has exported over $4 billion in product and services.
Australia	55	87	Australia's semiconductor sector global value chain contributions have not been separately tracked or reported over this period. Australia's overall ECI level is largely attributable to a low level of diversification among its exported goods (and services) and dominance within exports of primary resource sector intensive goods, such as iron ore, petroleum gases, coal and gold (collectively over 39 per cent of Australia's overall ECI export contribution by value, by just these four goods, with the tourism and travel sector representing a further 17 per cent. All of these sectors are graded as 'low' in the ECI calculus).[12]

Both Taiwan and Singapore are illustrative of economies that over the last 35 years have pursued deliberate, consistent, long range and successful, governmental policy, targeted assistance and capability-building to significantly advance their participation in the global semiconductor value chain.[13] Both serve as relevant case studies for Australia as Taiwan built a major semiconductor industry from a very low base, and Singapore's economy is less than half the size of NSW's.

1.3.1.1 Taiwan

Taiwan's share of the semiconductor market has increased from almost zero in the early 1990s to 7 per cent in 2014 and continues to increase. The Taiwanese semiconductor industry is also making a significant contribution to Taiwan's GDP through estimated exports worth US$61.2 billion in 2014 – a 16.3 per cent year-over-year increase.

Taiwan's rise in prominence in the semiconductor sector has much to do with TSMC and its founder, Morris Chang. A combination of circumstance, ambition and directed government action over many years provided the foundation for Taiwan's progression to become a powerhouse in the semiconductor sector. Chang was in his early fifties, armed with bachelor

[11] Note that Taiwan is not separately ranked in the ECI. Taiwan is included within China in the rankings.
[12] Atlas of Economy Complexity, *Australia Exports in 2018*, accessed 22 June 2020, https://atlas.cid.harvard.edu/countries/14/export-basket.
[13] Singapore was ECI ranked 20th in 1995 and 5th in 2018.

and postgraduate degrees in engineering from MIT and Stanford, along with 30 years' management experience in the US semiconductor sector, when the then Premier of Taiwan appealed to him to return to head Taiwan's Industrial Technology Research Institute (ITRI) with the express purpose of "transferring research results into economic gains for Taiwan industry".[14] This appealed to Chang's ambition and perception that the semiconductor sector was primed for a discontinuity through decoupling the design and marketing of chips from the manufacturing of the chips.

The Taiwanese government assisted the burgeoning venture by securing a licence to key but dated manufacturing technology from the US and, via ITRI, funding a team to go to the US for six months to undertake the know-how and technology transfer process. Although this manufacturing technology was two generations behind the then cutting-edge in the US and Japan, Chang and his team, with the support of the government, carved out a new business model that steadily attracted a diverse group of chip designers to utilise TSMC's facilities. The growing list of semiconductor startups designing new chips could not afford their own manufacturing or had difficulty in accessing the small fraction of manufacturing facilities that Integrated Device Manufacturers made available to third parties. With time, the capital expenditure saving to design teams and their funders made a compelling business case for this 'fabless' approach as a competitive model. Over subsequent years, the pure-play manufacturers and fabless design firms formed a mutually beneficial relationship.

It is instructive to consider Chang's own words from an interview he gave recounting part of this history:

> "…as I paused and thought about the task that Mr K. T. Li (the then Minister) gave to me … he wanted me to present a business plan, he wanted me to start a semiconductor company.
>
> "And another thread was what I had already observed, closely observed, for three decades. I had been in the semiconductor business for three decades before I came to Taiwan. And I learned at close quarters how competitive the industry was, and how good some of the players were – companies like Intel, Texas Instruments. Even then the Japanese companies were very fierce also. I knew how competitive it was, and how difficult it would be to carve out a niche for a new Taiwan company. So that was the second thread of thought.
>
> "The third thread of thought was to try to examine what we have got in Taiwan. And my conclusion was that [we had] very little. What strengths have we got? The conclusion was very little. We had no strength in research and development, or very little anyway. We had no strength in circuit design, IC product design. We had little strength in sales and marketing, and we had almost no strength in intellectual property. The only possible strength that Taiwan had, and even that was a potential one, not an obvious one, was semiconductor manufacturing, wafer manufacturing. And so, what kind of company would you create to fit that strength and avoid all the other weaknesses? The answer was a pure-play foundry. So maybe you could call it the least evil choice. The least evil because we've got no strength in all of these and I knew how difficult it was to compete even when you have strengths. It would be impossible to compete when you really had very little strength. But if we chose a pure-play foundry business model then we at least have the potential manufacturing strength that we can lean on. And we also manage to avoid the other weaknesses. We have no strength in design. We have a weakness in design. Well, we don't need design as a pure-play foundry. We've got no strength in sales and marketing. Well, sales and marketing for foundries is relatively simpler than sales and marketing for a conventional IDM company. At that time, the IDM model was the conventional model. In fact, it was the universal model. We got no strength in IP. Well, it turns out, at that

[14] SEMI, *Oral History Interview with Morris Chang (August 2007)*, accessed November 2020, www.semi.org/en/Oral-History-Interview-Morris-Chang.

> time, that process was the part that was least vulnerable to IP attacks from other companies. Most of the IP disputes were about circuit designs. So, in choosing the pure-play foundry mode, I managed to exploit, perhaps, the only strength that Taiwan had, and managed to avoid a lot of the other weaknesses."[15]

In November 2020, TSMC's market capitalisation exceeded US$400 billion, with annual revenue of over US$35 billion and growing at over 20 per cent per year. TSMC's headquarters are located in Taiwan's Hsinchu Science Park. In 1998, 109 out of 222 firms in Hsinchu Science Park were founded by returnee entrepreneurs educated and trained in the United States. Hsinchu Science Park has gone on to become one of the largest hubs for semiconductor manufacturing talent in the world.[16]

1.3.1.2 Singapore

In 2018, the Singaporean semiconductor sector accounted for 7 per cent of Singaporean GDP or A$36 billion, employed around 35,000 people, and represented approximately 11 per cent of the global semiconductor market. For reference, Singapore's population (5.8 million) is comparable to Sydney's population (5.9 million). In 1960, Singapore was viewed externally as a struggling economy with GDP per capita of US$1,300. At the same time, Australia's was 40 per cent higher. By 2019 however, Singapore's GDP per capita was approximately US$65,000, and Australia's was 15 per cent lower.

In 1961, four years before its formal independence, Singapore created the Economic Development Board (EDB) to initiate and accelerate industrialisation. The EDB's program, focused initially on import substitution and job creation, compromised three main themes:

1. Attracting Multi-National Corporations (MNCs) with incentives to locate new facilities into Singapore and thus begin a process of technology knowledge transfer via the natural flow of on-the-job training and worker mobility, as well as steady technology upgrading over time.
2. Targeting promotion strategies, publishing strategic priority industries and fitting industry value chain entry strategies to Singapore's strengths in labour availability. These were well suited initially to the assembly, packaging and test 'jobs to be done' functional steps in the semiconductor value chain, and eventually led to Singapore advancing into adjacent semiconductor value chain steps requiring greater know-how or capital intensity.[17]
3. Executing of a comprehensive set of 'preparatory steps', including: provision of infrastructure; development finance; investment incentives for foreign firms; active sourcing of investment; labour and human resources; as well as acquisition of technical skills through university and technical training.[18]

Not everything went entirely as desired, some MNCs came and went with the vicissitudes of business. When the global economic recession hit in the 1980s many MNCs retreated to their home markets, leading the EDB to emphasise policies directed towards supporting local companies. The EDB encouraged Singapore's state owned enterprises, who often dominated critical infrastructure and security-sensitive areas of the Singaporean economy, to take on more advanced activities which the departed MNCs once undertook and also to become more commercially and export market-focused. In the 1990s Singapore turned its focus towards commercially minded R&D, following in part the Taiwanese example of

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[15] SEMI, *Oral History Interview with* Morris Chang *(August 2007)*, accessed November 2020, www.semi.org/en/Oral-History-Interview-Morris-Chang.

[16] Song, J. 2000, '*Technological Catching-up of Korea and Taiwan in the Global Semiconductor Industry: A Study of Modes of Technology Sourcing',* APEC Study Center Discussion Paper Series no. 15, December 2000.

[17] Academic frameworks to many of these value chain insertion and expansion activities are discussed in Mathews, J.A. 1999, *A Silicon Island of the East – Creating a Semiconductor Industry in Singapore*, California Management Review.

[18] Singapore's industrialisation approach is discussed in Mathews, J.A. 1999, *Encouraging knowledge-intensive industries: What Australia can draw from the industrial upgrading experiences of Taiwan and Singapore*.

building a range of institutional capacities. These included an ITRI-like market-scanning and informational seeding function, embedded within the Agency for Science, Technology and Research (A*STAR) – an organisation credited with leading Singapore's Research Innovation and Enterprise efforts to transform the city into a knowledge-based, information-intensive economy.[19]

1.3.1.3 The role of government

What is evident from the examples of Taiwan and Singapore is that there is considerable fertile ground between the old extreme arguments of 'no touch' market efficiency versus the 'total command and control' of centralised government when it comes to how prosperity and productivity are advanced.

Rather, as Mathews emphasises in *Encouraging knowledge-intensive industries: What Australia can draw from the industrial upgrading experiences of Taiwan and Singapore,* 1999, (at page 5):

> "The key to the successful restructuring and upgrading engaged in by firms in Singapore and Taiwan, lies in the institutional environment which shapes their decisions. Both countries have fashioned a set of institutions which drive firms in these economies towards an outward, export orientation and towards endless technological upgrading – rather than allowing firms to take the easy option of competing on the basis of cost minimisation."[20]

> "It is firms which generate the wealth in Singapore and Taiwan and they do so through making their own strategic decisions. But they operate within an institutional environment which biases them towards investing in strategically important industries, and in technological upgrading, that has the effect of enlarging their strategic options."[21]

In hindsight economic arguments based on national economic benefit alone could have justified much deeper and substantial investments by Australia into the semiconductor sector historically. While not discussed in detail in this study, strong new arguments can be made today based on broader economic assessment frameworks, and increasingly also on national security and strategic grounds to forge greater participation in global 'apex' value chains such as the semiconductor sector.

As the countries noted above have demonstrated, in dynamic markets absolute and comparative advantages are not fixed, nor are the dimensions fixed on which competition plays out over time. Rather than a sole deterministic focus on labour costs and lowest unit 'prices', whether mediated by efficient markets or national industry policies, many other dimensions are relevant in determining what activities a country should pursue and seek to maintain and improve upon. End markets, for example, can value reliability, design, financial support, service support, risk management, provenance, trust or security, as well as price. Indeed, business models based around customer-value or value pricing emphasising distinctive features and benefits valued by each customer, even in what would otherwise be considered commodity markets such as meat and seafood, illustrate that low price is not the only path to a successful strategy.[22] Of course, to implement such strategies capabilities, assets and relationships need to be developed.

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[19] Chodhury, A.R. 2016, *"A*Star surpasses 5-year targets; industry R&D spend exceeds S$1.6b",* The Business Times, 26 April 2016, accessed November 2020, https://www.businesstimes.com.sg/technology/astar-surpasses-5-year-targets-industry-rd-spend-exceeds-s16b.

[20] Mathews, J.A. 1999, *Encouraging knowledge-intensive industries: What Australia can draw from the industrial upgrading experiences of Taiwan and Singapore,* 5.

[21] Ibid*,* 7.

[22] Dholakia, U.M., 2016, "A quick Guide to Value-Based Pricing", Harvard Business Review, 9 August 2016, accessed November 2020, https://hbr.org/2016/08/a-quick-guide-to-value-based-pricing.

A discernible global trend is also emerging where countries and businesses are increasingly conscious of externality management, responsibility and accountability – particularly with respect to the environment, social and governance (ESG) factors.[23] Moreover, governments are also appropriate institutions to monitor and promote the upside of positive spill-over benefits. These include tuning the levers which generate economic multiplier effects up, down and across related value chains. It also includes valuing and nurturing future optionality for the country in the forms of knowledge uplift, knowledge pooling, knowledge sharing and innovation infrastructure, including effective innovation translation processes.

The seven foundational horizontals (across the bottom of the semiconductor value chain shown earlier in Figure 1) are intended to bring into focus these important wider institutional and environmental factors in the long term dynamics of global value chains. Where there are apparent frictions, failures and deficiencies in self-correction or self-regulation of markets it becomes the role of government to assess and tend to these largely policy driven factors.

If nothing else government's role in setting industry, innovation, technology and trade policy and their effective implementation impacts direct employment opportunities in the jobs for today or laying the foundations for jobs in 10 or 20 years' time.[24]

As Michael Porter stated in *The Competitive Advantage of Nations*, 1990, (at page 19):

> "Competitive advantage is created and sustained through a highly localised process. Differences in national economic structures, values, culture, institutions, and histories contribute profoundly to competitive success. The role of the home nation seems to be as strong as or stronger than ever. While globalisation of competition might appear to make the nation less important, instead it seems to make it more so. With fewer impediments to trade to shelter uncompetitive domestic firms and industries, the home nation takes on growing significance because it is the source of skills and technology that underpin competitive advantage.

Australia is starting from a low base in many respects due to a present lack of broad and deep participation in the global semiconductor sector. However, Australia has a set of relevant assets and existing capabilities which are highly valuable and leverageable. This study considers the Australian semiconductor landscape and how NSW and Australia can enable, enhance, promote and expand its strengths to be more than competitive in the current and future global semiconductor market, as well as those upstream and downstream markets linked to semiconductors.

[23] See, eg, The United States Business Roundtable, 2019, *Business Roundtable redefines the purpose of a corporation to promote 'an economy that serves all Americans'*, 19 August 2019, accessed 20 November 2020, www.businessroundtable.org/business-roundtable-redefines-the-purpose-of-a-corporation-to-promote-an-economy-that-serves-all-americans. See also Porter, M.E. and Kramer, M.R. 2011, *Creating Shared Value*, Harvard Business Review, https://hbr.org/2011/01/the-big-idea-creating-shared-value.

[24] See, eg, Janeway, W. 2012, *Doing Innovation in the Capitalist Economy: Markets, Speculation and the State,* Ch 10.

2 STUDY OBJECTIVES AND APPROACH

This study, conducted for the Office of the NSW Chief Scientist & Engineer, examines Australia's semiconductor sector's capabilities, needs and opportunities, and is based on over 100 one-on-one and group interviews with sector leaders.[25]

The primary objective of the study was to determine if, where and how NSW and Australia might more meaningfully participate in the global semiconductor value chain. The methodological approach was to establish two primary streams of questions:

1. The first set of questions and analysis focused on ascertaining NSW and Australia's current participation in the sector across the whole value chain and where inhibitors to semiconductor-related business addition and growth arise, including barriers to entry.
2. The second set of questions and analysis sought to evaluate, place and project NSW and Australia's existing and potential participation in the semiconductor sector in terms of global competitiveness. This included assessing capability and 'assets', global market dynamics across a range of value chain positions and end markets, and prospective global market discontinuities where Australia may be well positioned to carve out a niche or leading position.

A synthesis of the findings, guided by these two primary questions, suggested underlying themes, or 'levers', around which actionable policy and implementation initiatives could be undertaken. This included evaluating international case studies for policy options and alternatives. There is a wide range of potential initiatives, each with their own benefits, costs and risks. The benefits can be maximised where a more comprehensive set of initiatives is adopted.

The analysis of needs and challenges considered the root causes for Australia's present low relative standing within the global semiconductor sector. That is, what has inhibited our participation in this sector. Many of these 'root causes' are common across Australian industries, not just the semiconductor sector.

[25] Interviews were conducted in July and August 2020.

3 AUSTRALIAN CAPABILITIES, CHALLENGES AND OPPORTUNITIES

3.1 CHALLENGES IN THE SEMICONDUCTOR SECTOR

In examining where Australian semiconductor sector-related capability existed in 2020, this study focused on the commercial sector (as distinct from the public research sector). As a whole, Australia's existing participation in the global value chain is well under-weighted for an economy of our size and maturity. There are few Australian companies designing their own chips, Application Specific Integrated Circuits (ASICs), optical sensors or Photonic Integrated Circuits (PICs). During consultations, many challenges were advanced for this low participation. The challenges noted generally varied by type of company.

3.1.1 Large companies

This study was unable to uncover a major Australian company,[26] whose core business activity is participation in the semiconductor design, development and production value chain.

In general, Australian companies are adopters of platforms incorporating semiconductors and as a result are, in effect, reasonably efficient regional 'branch operators' or 'hosts' of other countries' technology. Being a fast adopter has some benefits, including avoiding the development costs of misfired technology efforts. However, in focusing on adoption rather than development, Australia incurs an opportunity cost by failing to capture value from control and ownership of the significant stages of the initial product and service realisation processes – born from R&D, IP discovery, protection, productisation, commercialisation and industrialisation. This is as apparent in the semiconductor sector as elsewhere.

Moreover, Australian industry is not creating an effective demand signal for the supply of relevant local semiconductor sector products or services; nor is it translating relevant research into marketable products in this area.

Many leading Australian businesses rely on the outputs of the global semiconductor value chain. For example, Telstra relies on wireless base stations, handsets and routers that are powered by semiconductor chips; Appen relies significantly on a growing market for cloud- and device-based GPU and AI chips to provide demand for their machine learning and artificial intelligence training services.

The key challenges noted by Australian large companies for greater direct participation in the semiconductor sector included:

Challenge 1 – Market risk: Leading Australian businesses are reluctant to take on and manage the risks inherent in the highly competitive semiconductor sector. These businesses: do not have any affinity for the sector; nor do they have local role models; they are not encouraged by capital providers, financial analysts or the press; they have little, if any, personal or professional training in the sector; and they lack practical experience. They are also wary of the 5-10 year investment cycles generally required in the semiconductor sector and the extremely large investment requirements – that are, on a relative and absolute basis, amongst the largest for any sector. Competitiveness in many markets of the semiconductor sector is driven by lowering the chip piece rate as low as possible – hence very large investments in massively scaled, highly automated fabs are necessary to be

[26] For example, there are none in the ASX200.

competitive. For example, the latest US Government and TSMC announcement for a single new semiconductor fab in Arizona has a capital cost of US$12 billion.

Challenge 2 – IP barriers: There are significant IP barriers to contend with – the semiconductor sector being one of the most highly patented and where it is generally easy to spot transgressions.

Challenge 3 – Scarcity of talent: In this internationally competitive sector, there is a shallow local pool of relevant talent. Yet talent and know-how, which can take decades to accumulate, is vital in this sector given that the semiconductor design, development and production processes are very complex.

Challenge 4 – Domestic market focus: Australian senior executives of large companies confided during the consultations that they understood that the semiconductor sector is in large part a globally competitive market, but that few Australian companies are comfortable competing globally, preferring to focus on competition domestically or in niche end-use sectors.

3.1.2 Startups and scaleups

Many of these same challenges also affect Australian startups and scaleups active in or considering participating in the semiconductor sector. The lack of large companies participating in the sector also affects them indirectly because there are no local role-model large companies, no enduring success stories, few representative local end-customers to engage early and closely with to gain critical market intelligence, and no logical local acquirers for their business, let alone for their products. There are also particular challenges facing the startups and scaleups.

Challenge 5 – Risk capital shortage: There is a shortage of local capital for semiconductor start-ups, and what capital is available is limited to supporting a few ventures, adds little additional value beyond the funding itself and is usually steered by general partners with no first-hand experience of operating a semiconductor sector company themselves.

Challenge 6 – Absence of informed local customers: Without any significant Australian companies represented in the global markets today, the critical element for any business – end-market relationships – are missing. This makes it difficult to track and respond to rapidly evolving value propositions and device performance requirements. Without significant end market understanding (market intelligence) a startup or scaleup's technology and product roadmaps are not sensing one of the key early signals a market has to offer – and therefore are likely to be poorly calibrated from the beginning.

Challenge 7 – Expensive design tool-chains: Australian startups in the sector are also hit with large chip design electronic design automation (EDA) and computer aided design (CAD) fees, such as for the Cadence, Synopsys and Mentor Graphics tool-chains. These fees frequently are in the high tens of thousands of dollars per seat licence per year, well in excess of the licencing fees that regular software development companies incur.

Challenge 8 – Prototype fabrication: There are no Australian facilities that can commercially fabricate local chip designs and very few facilities to appropriately test and validate early prototypes for scaling to production. All of these value-added steps currently go overseas, increasing logistic and administrative burdens, costs and turnaround times.

3.1.3 Applied research

These environmental conditions also obstruct Australia's applied research efforts (research directed at a Technology Readiness Level (TRL) beyond level 3 (TRL>3)). Often described as the technology 'Valley of Death', applied semiconductor research suffers from: limited availability of trained technicians, postdoctoral researchers and process engineers; little clear validation of the merits of investors' and industry's 'will it work' questions; expensive tool chains; and difficulties in finding and working with 'fit-for-purpose' prototype fabrication facilities. These burdens incentivise basic semiconductor research at the expense of applied semiconductor research.

That many of these nascent applied semiconductor research activities are offshored, abandoned or not even commenced, is presently justifiable on an existing economic cost basis for each isolated project. However, the lack of applied research is much less justifiable on an aggregate or total national cost basis, as some of these projects could be successful, delivering outsized benefits that outweigh the aggregate investment across multiple projects.

3.2 AUSTRALIAN CAPABILITIES IN THE SEMICONDUCTOR SECTOR

Despite the challenges noted above and the general observation that Australia's presence in the sector is underweight, there are pockets of world-class capability that do exist in Australia. This capability, talent, expertise and value delivery capacity could be leveraged into a large industry presence. However, this will likely require a significant set of 'root and branch' initiatives – to both address frictions and failures in the Australian semiconductor sector and Australia's broader innovation system.

Australia's recognised strengths in a number of areas relevant to the semiconductor sector are discussed below.

3.2.1 Radio frequency communications, radar and photonics

The consultation process revealed that Australia's semiconductor design capability is world-class in radio frequency (RF), millimetre wave (mmwave), photonics and radar. These areas were all generally acknowledged even by parties external to Australia, including Defence Primes, but also in the consultations held with international representative companies, including Broadcom, Qualcomm, AMD, Intel and Applied Materials.

While most of the Australian RF and mmwave talent is within Australian-based design centres or groups, owned, controlled and managed by MNCs, these individuals and teams are highly rated for their expertise, experience and delivery capabilities. Such talent pools provide high potential for Australian-based start-ups or the further encouragement of international companies to base portions of their semiconductor design development in Australia.

Most of the limited ASIC chip design activity is focused on RF Comms, almost entirely for 5G but also for some defence sector-related applications. There is a much wider and deeper pool of field-programmable gate array (FPGA) design engineers and programmers – covering specialised applications in mixed signal and data communications such as satellite communications, high-frequency trading, audio, video, radar, sonar and telemetry. It is important to note that FPGAs are designed on and programmed post-fabrication – they are bought without the risk, expense or hassle of having to go through tape-out and manufacture – which are key reasons for their relative prevalence in Australia.

3.2.2 Basic materials

With over four decades of long-term growth in the semiconductor sector, the range of applications (and hence performance and cost requirements) of semiconductors has proliferated, creating many new device (logic, memory, analogue, sensing, opto-electronic, photonic, discrete) and end-user and industry markets (from automotive to medical, from industrial to consumer etc).

In recent years the semiconductor technical progress underpinning complementary metal-oxide-semiconductor (CMOS) fabrication, often summarised as 'Moore's Law', appears to be reaching its limits, although there are many dimensions for size, weight, power, cost and integration improvements being explored. A number of these dimensions are enabled by the properties found in non-silicon materials, including rare and critical materials such as hafnium, bismuth, indium and rhenium. At the same time, a 'bifurcation' of semiconductor material platforms away from silicon primacy towards 'composites', such as gallium arsenide, gallium nitride and indium phosphide, is exploiting a range of 'band gap' properties in these materials to meet exacting end-use requirements for power electronics, radio-frequency and optical applications, amongst many other markets.

Australia has known deposits and reserves of a number of these key contributing materials. Australia also has sizeable deposits of silica, relevant to CMOS semiconductors. While we would need to quickly develop, absorb and scale process knowledge for the beneficiation and processing of such materials, Australia, as a whole, has a significant pedigree in the exploration and extraction of minerals more generally. Where our mineral endowments meet with related mining capability strengths and Australia's world-class material science R&D capabilities there is a semiconductor-related opportunity for Australia, albeit in a lesser accentuated, but still critical part of the global value chain.

3.2.3 Basic research

Australia's basic research credentials, led by many of our world-class universities and the CSIRO, are highly regarded within the global academic community. Australia as a whole, and certain institutions, are rated highly for publications and citations in many disciplines. Individual academics and teams, centres and institutes across numerous fields could apply and extend their knowledge creation to critical 'frontier' areas within the semiconductor value chain – from materials science, to novel power management, communications and sensor applications.

It is relatively easy to find Australian basic research expertise on the global frontier across many disciplines related to the semiconductor value chain: in material science and chemistry and physics; communications, especially in photonics; nano-technology; quantum computing and sensing; neuromorphic computing and many other areas. However, this observation comes with two critical caveats: there is very little basic research going into semiconductor-related processes directly; and the translation rate from basic to applied research (and beyond into translation) needs to be significantly improved. Arguably, this will remain the case in Australia until there are meaningful cultural, institutional and incentive changes made. In particular, in incentivising the *delivery and capture* of value via end-use technologies in the marketplace that are owned and controlled by Australian businesses, not just the prestige garnered in the *discovery* of value represented by publications.

Promoting industry-informed problem-solving research programs, indigenous company engagement and 'skin in the game', and improving translation and commercialisation processes remains an abiding set of tasks for Australia to advance economic and societal returns from its basic research investments. It is notable that Australia has made solid early steps to position some quantum-sector basic research programs into this 'triple-helix' framework, well in advance of the quantum value chain fully coalescing and end-use markets maturing. As there exists high potential spill-over benefits from semiconductor-related skills, capabilities, assets, relationship and learnings into the quantum sector, there are potentially greater aggregate benefits from investments made today in semiconductor programs.

3.2.4 Value chain participation more generally

Conceptually the semiconductor value chain moves downstream along the value chain, from inputs and intermediate processors, though IP and design, then fabrication and on towards end-markets. Initial inputs are raw sand or bauxite, and chemicals and equipment for early stage processing to get to ingot production, then to dopings and depositions. The next part of the value chain is chip design and IP blocks. The chain then proceeds onto fabrication. Again, Australia presently has no representation here in strictly defined commercial fabless manufacturing. However, Australia has some prototyping facilities, isolated examples of emerging, low volume niche market fabrication and one in-house automotive diode fabrication facility. Post fabrication there are a number of Printed Circuit Board (PCB) assemblers placing purchased semiconductors onto boards and then into equipment.

Across the value chain Australia has very shallow participation in the semiconductor sector, apart from in fabless design, after-fabrication software programming and then in local sales and distribution of final equipment with embedded semiconductors. There are some notable credible exceptions. ANSTO, for example, is recognised as a valued international market supplier in highly specialised semiconductor ingot doping. ASTC, Perceptia and Radlogic are long-standing independent integrated circuit and semiconductor IP design houses – but actually perform a range of other important jobs on behalf of their clients. An influential role at the end-market step of the value chain in the defence sector are the international Defence Primes, as exemplars of system integrators, who develop the multitude of systems and sub-systems that incorporate semiconductor chips with very specific performance requirements – many of which are procured by the Australian Defence Force (ADF) but not typically in large volumes or with direct commercial market applicability.

During the consultations it became apparent from direct and indirect commentary that it was important to distinguish between the ownership and control of the companies participating in Australia's semiconductor sector. The greater ownership and control by Australians, the greater the prospect for local value-added flexibility to go up and down the value chain, with the greater likelihood of spurring new businesses and a stronger foundation for future industries (such as quantum computing) to have higher retention in Australia. One key indicator of this greater latitude and prospect, beyond mere ownership percentage and un-observable control rights, is the presence of the Product Manager with global profit & loss and future product roadmap responsibilities being located in Australia. The Product Manager links the present to the future, the market to the firm, the present product to the future development. Invariably Australian organisations with the highest value-add potential have locally-based Product Managers. Branch offices of semiconductor related MNCs operating in Australia, even those doing sophisticated integrated circuit design work here, work under Product Managers not located in Australia and consequently are more susceptible to the natural corporate whims and opportunities to place value-added activities elsewhere.

This distinction between 'Australian' and MNCs firms was particularly informative when it comes to the 'fabless' chip design and programming of chips value-adding stages in the semiconductor value chain. FPGAs, Embedded and Firmware, and Digital Signal Processors (DSPs) do not require chip manufacture *after* the design or programming (see Figure 2). They do often require subsequent PCB manufacture and Electronic Contract Manufacture (ECM) and Assembly, Packaging and Test (APT), but not chip manufacture – the chips themselves have already been manufactured overseas. To be clear, the design and programming are important, high-value, skilled jobs. These are jobs which Australia should continue to seek to attract and grow. It is also desirable to have more Australian content, formal IP expertise, ownership and control, and Australian management positions (including Product Managers), to maximise value creation, delivery and capture in and for Australia.

There is a long and strong history in Australia in certain sectors of Application Specific Integrated Circuit, or ASIC, design. However today, there are only a few Australian-owned and controlled companies working on their own ASICs locally. Even this small presence is under threat. Australian companies have in recent times moved their ASIC design not only off-shore but also out-of-house entirely. Startups and scale-ups constantly weigh up how much design work they continue to do here in Australia as opposed to, say, Bangalore, Irvine or Dublin. What is clear is that Australia's comparative advantages are in RF comms, moving up into mmwave, photonics and radar. There are future points of convergence between some of these markets, which a number of startups and growth companies are targeting. There are likely paths from these markets into space-based applications (especially, for example, in the terahertz domain), and foundationally, in a related skill sense, into quantum applications.

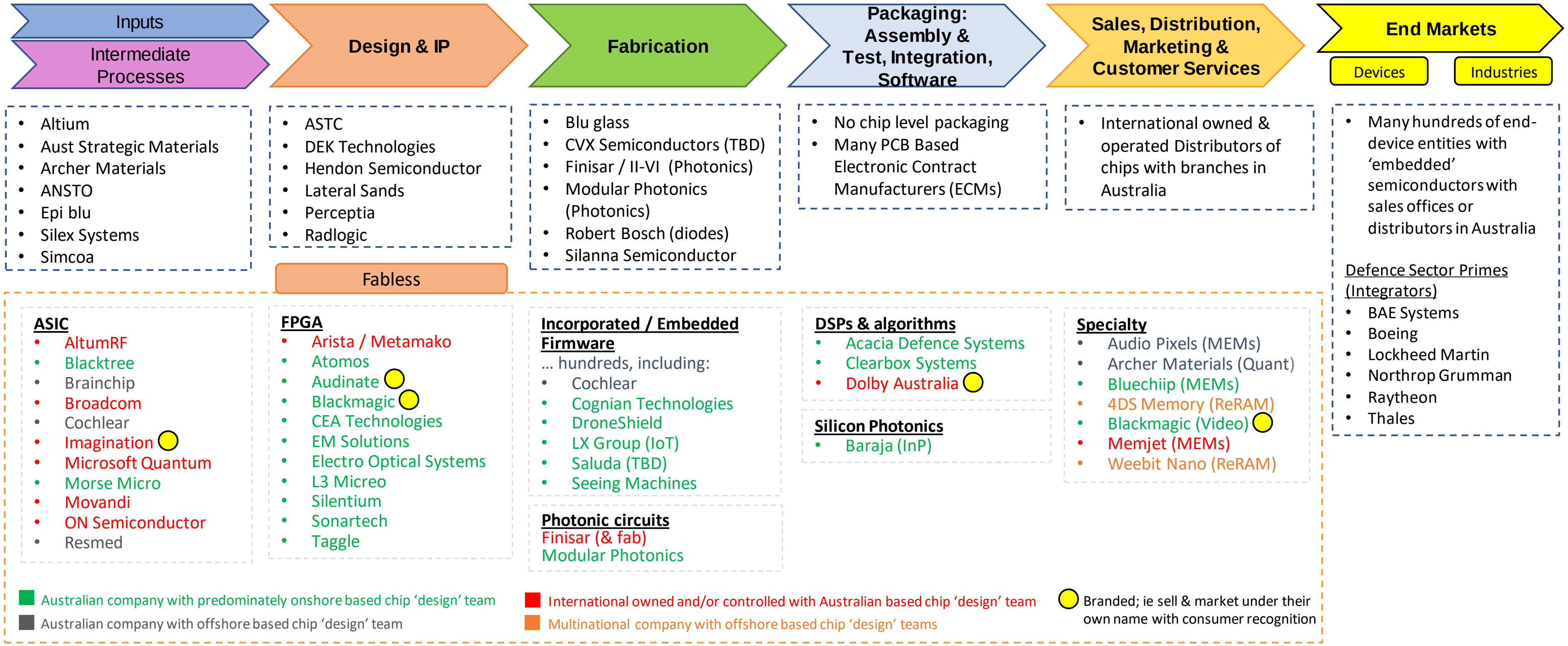

Figure 2: Representative Australian participation in the semiconductor global value chain

3.3 SEMICONDUCTOR VALUE CHAIN CHARACTERISTICS

The semiconductor value chain is vast and complex, and this study seeks to make broad general observations around Australia's capabilities, opportunities and challenges in this sector. However, there would be value in an ongoing market intelligence capability for this sector. Such a capability would, over time, identify further detail and inform and guide particular granular 'instances' for research, innovation translation, startups, and investment attraction. Key points on parts of the semiconductor value chain raised during the consultation process and secondary research are noted below and in Figure 3.

3.3.1 Silicon-based semiconductors

In terms of chip fabrication roughly 90 per cent of the overall sector is still silicon-based, dominated by the maturity and scale of CMOS process technology. While the number and sophistication of chips continues its long-term growth trend, Moore's law strictly is no longer applicable. Moreover, it is costly and risky, even for major players such as Intel, to pursue ever more sophisticated chips with smaller node chips. Further, with Intel increasingly likely to move to external fabrication for their most advanced node processing – this will inevitably have a 'cascading bump' on smaller players access to new nodes causing disruption in the normal market cadence of some product releases.

There are, however, plenty of existing and new device and application markets suited to older node processes (for example, 28nm, 40nm and upwards). Australian fabless design companies definitely have shots at using some of these older node processes to pursue viable business cases. These older node processes are, at this point in time, generally still accessible to our fabless design firms. In this scenario, Australia does not necessarily need its own silicon plant.

Of course, a local silicon plant would have clear benefits including for absolute assured supply, potential market leverage (strategic) and the positive external spill-overs, short-term and long-term, to domestic semiconductor (and related) markets. However, Australia is not well placed to enter the CMOS market in its own right nor as the 'lead' partner. Without an experienced joint venture partner providing the operational and process expertise on an economical, timely basis, the (non-capital) barriers to entry and performance that Australia faces are likely to be too high at present.

Assuring relationships with a geographically and geopolitically diversified set of existing CMOS fabrication vendors is a smart 'Australian strategy'. Building and maintaining credibility, knowledge flows and flexible arrangements with these CMOS fabrication facilities are critical factors for continued ongoing access for Australian businesses on an equal basis with international businesses. This is also important for the feasibility of Publicly Funded Research Institute (PFRI), university-based and startup semiconductor prototype and first-time scaling projects.

Because of the barriers to entry into CMOS fabrication, Australia ought to ensure that Tier 1 or Tier 2 silicon-based semiconductor fabricators are aware that it would look favourably on the establishment of fabrication facilities here in Australia. Australia would certainly benefit from the technology transfer and local eco-system development (assuming other foundational capability-enabling steps are also taken). Such is the magnitude of the possible long-term positive spill-over/multiplier effects, as well as sovereign capability and security benefits for a nation and region from local fabrication capabilities, however, that subsidies and incentives have become a widespread part of the global attraction game. These incentive packages need to be carefully scrutinised, including: (1) the other deal terms beyond funding (for example, minimising the 'socialisation of losses and the privatisation of profits'), and; (2) government directly and equally supporting and incentivising the other critical supporting foundational ecosystem elements rather than solely just the industry attraction (for example, related research and commercialisation capabilities). Major semiconductor fabricators will not do this heavy-lifting themselves, and if left to their own account will likely naturally skew the foundations in their direction.

Financial incentives alone are not sufficient to attract Tier 1 or Tier 2 silicon-based semiconductor fabricators. But additional potential attractors Australia may offer include:

- Japan and South Korea may also see national value in working even more closely with a Five Eyes partner such as Australia, while diversifying their existing direct engagement with either the US or Europe.
- Australian liveability should not be discounted as a factor in senior executive decision making around plant location.
- Proximity to raw materials, including rare and critical earth materials could also be a motivating factor to locate a plant here for a number of critical components and defence-orientated companies.
- An Australian CMOS facility would assist a fabricator to garner a 'first look' on a location basis to Australia's quantum endeavours favouring a CMOS-based approach.

3.3.2 Composite, or compound, semiconductors

Around 10 per cent of the semiconductor sector is focused around 'non-silicon' ('composites', for example, GaN, GaAs, SiC, InP), power transistors and photonics. On average, these composite chips have higher prices and a strong market position can generate significant profit. The combined set of composite semiconductor markets is already large and growing quickly – US$32 billion in 2020 and forecast, on some estimates, to be approximately US$43 billion by 2025, and US$67 billion by 2027.[27]

The end-use markets for these compound semiconductors include power electronics, military, defence and aerospace (especially RF, mmwave and terahertz, radar and avionics), and LEDs. The strategic significance of these end-use markets increases the sensitivity of supply-chains, sourcing and diversification, including access to raw materials, refining, associated epitaxy and fabrication.

Most composite fabrication plants are 'captive', in the sense they are owned and almost exclusively utilised by a chip design and marketing company (that is, they are Integrated Design Manufacturers (IDMs)). Nearly all of the US Defence Primes have their own US Department of Defence GaN 'Trusted Supplier' status foundries. Historically, from time to time these facilities are over-ordered and second-sourcing of fabrication is required. This often occurs to all the Primes at the same time, so they cannot always deal between themselves to alleviate demand crunches. In these circumstances, and potentially others, a reliable, trusted second source for the Defence Primes exists.

For an Australian GaN (or similar, say, GaO) plant to be feasible would likely require: (1) a joint venture partner or consortium (for example, the Defence Primes) with direct operating experience of a state-of-the-art composite foundry, and; and (2) a related 'co-design' and/or 'co-creation' capability to assist local Australian firms design for, access and optimise for the particular fabrication process supported by the indigenous facility.

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[27] Markets and Markets, 2020, *Compound Semiconductor Market with COVID-19 Impact Analysis by Type (GaN, GaAs, SiC, InP), Product (LED, RF Devices, Power Electronics), Application (Telecommunication, General Lighting, Automotive, Power Supply), and Geography - Global Forecast to 2025*, https://www.marketsandmarkets.com/Market-Reports/compound-semiconductor-market-178858112.html. Note that some forecasts by other market analysts using different methodologies have even higher estimates.

Inputs / Intermediate Processes

- Australia comparatively well endowed in raw materials, but very limited value-adding and little to none end-market connectedness
- Materials will be a key (necessary but not sufficient) basis for new semiconductor advances
- Semiconductor Equipment Market is highly fragmented and specialised in early stage markets but ‘monopolies’ (IP & know how) at the ‘top end’; very good financial returns in defensible niches but subject to market volatility
- Commercial tool-chains for chip design are expensive
- Possible Test & Measurement market opportunities

Design & IP

- Relatively modest capital investment required to start-up (compared to fab-based model)
- Market Intelligence for ‘right’ product required
- Access & retention of design skills; Remote workers as a major discontinuity to previous location centricity
- Can be inconsistent access to cost effective and quick turn-around time for fabrication of designs. Pilot runs: occasionally fab process “tweaking” very important
- Scaling to Marketing & Sales often problematic, including Access to Markets
- Designing to a customer’s requirements

Fabrication

- Huge capital investments required
- Complex know-how to operate and maintain
- Often long-lived product cycles and fab assets: drives products & fabs to marginal profitability
- Often rapid and steep price declines as capital is sunk
- Consolidation amongst IDMs with fabs
- Marginal profitability; poor ROI amongst the over 400 fab providers, incl the ‘captive’ fabs.
- Market distortion from massive country/state/city subsidies (eg China)

Packaging: Assembly & Test, Integration, Software

- Large capital investments required
- Complex know-how; largely labour based but some robotic process opportunities
- Non-standard processes in many cases
- Labour intensive
- Around 40-70% of the chip cost, but declining with automation
- Often located near related fabs & emerging ‘professionalising’ labour pools

Sales, Distribution, Marketing & Customer Services

- Market access with no prior track record (trust) or Balance Sheet (suable) is very difficult, expensive and market-context & time-dependent
- Typically requires bearing large Working Capital & Risk burdens
- Modular chips with standardised interfaces makes for ‘socket replacement’ risks and, hence, price weakness overtime

End Markets (Devices | Industries)

- Active refresh of products in markets – generally incremental innovations, occasionally an entirely ‘revolutionary’ new platform with value-chain reconfiguration rippling effects and emergence of new players
- Active start-up entrants often consolidated into existing companies once product gains traction; Acqui-hiring of distressed start-up teams
- Markets generally require strong signal of fabrication support and semiconductor supply capacity before moving enmasse to new technology platform

Figure 3: Broad characteristics of the semiconductor value chain relevant to Australia

3.4 ACTIONABLE LEVERS TO GROW THE AUSTRALIAN SEMICONDUCTOR SECTOR

Based on the identified challenges facing Australia in the semiconductor sector, as well as areas of relative strength, this study identifies potential initiatives to grow Australia's participation in this sector. The collective set of potential initiatives include, but are not limited to, these 'lever' areas:

Table 2: Levers to grow Australia's semiconductor industry

Knowledge, skill and competency enhancement	Enhancing local knowledge, skills and competencies – from K-12, though: university curriculums and instruction improvements, to a new emphasis on vocational and applied skills, up-skilling and retraining; streamlined procedures around supplemental talent identification and 457 Visa processing; proficiency of (semiconductor-related design and process) engineering skills, including tool-chain familiarity; and global talent identification and local recruitment facilitation.
Capital access	Improving access to capital for startups, scaleups and growth ventures via focused Venture Capital funds with sector-hardened general partners.
Research Translation	Providing translational support from basic to applied research, including commercialisation and industry collaboration, access to 'best fit' prototype-to-scale infrastructure and addressing non-trivial barriers to entry and scaling.
Financial incentives	Expanding financial incentives within the R&D Tax Incentive scheme towards 'beyond business as usual' collaborative R&D between industry, defence, universities and PFRIs, particularly for semiconductor-related endeavours.
Eco-system development	Increasing local, regional and national eco-system development efforts to provide 'network' learning opportunities and coordinated sector lobbying into sustained policy directions.
Market intelligence	Establishing a 'single point of contact' national market intelligence capability in relevant global technology markets to inform long-term national policy development and program execution, strategic partnership activities and opportunity identification and facilitation across government and its agencies (for example, Austrade), university and publicly funded research sectors, industry and defence.
Government procurement	Ensuring a critical role for the Australian Defence to promote and lead domestic 'dual-use' IP creation, designs, use and ownership and control retention, with government procurement imperatives for local semiconductor IP and content.

In addition to the levers in Table 2 above, an overall finding of this study is that Australia needs to match:

1. Sectors where likely profitable opportunities are emerging ('emerging market opportunities'), with
2. Australia's existing strengths and endowments ('Australian advantages'), and
3. 'Step-wise' but long-term commitments to investment, capability building and coordinated competitive strategies to ensure value creation, delivery and capture ('capability and capacity-building').

These elements are discussed below.

3.4.1 Emerging market opportunities

The global semiconductor sector has undergone constant change. A number of factors point to the semiconductor sector's continuing importance and complex dynamics:

- Economic prosperity, security and technology market growth being dependent on the semiconductor sector, with potential for wealth and power divergences.
- Concerns over the limits of Moore's law, leading to novel and divergent approaches to improve performance through gate-all-around transistors, 'application-focused' chips, chiplets and new integration and packaging approaches.
- An expanding outlook for novel semiconductor platforms, such as composites and compounds, which exploit the unique properties of new or thus far not fully explored

materials which are favourable to meeting performance requirements of new and ever-growing use cases.
- Hardware, communication network and artificial intelligence security becoming a much higher profile issue within the context of cyber security more generally.
- The continuing interplay and misalignment between expanding data flows, communication needs, memory requirements and processing capacity – whether it is, for example, deep inside hyperscale data centres, at the edge, in IoT or in nano-device body implants.
- A growing increased concern for energy and sustainability issues related to semiconductor value chain steps, including the energy use of compute resources.
- Sensing, perceiving and reasoning of real-world ‘events’ by machines at or well beyond human capabilities and their ‘governance’.

These factors are generating many new, niche semiconductor opportunities. This is despite consolidation,[28] especially in the advanced node (sub 7nm) CMOS fabrication segment and seeming dominance of large market-facing brands, particularly in consumer and some industrial sectors. Country-specific national security concerns have created new enthusiasm for Australian in-country sovereign supply-chain opportunities in critical technologies,[29] including those related to semiconductors.

In addition, other themes beginning to impact the semiconductor sector more broadly include the rise of RISC-V, the evolution of FPGA functionality towards hybrid and adaptable hardware, emergence of flexible and printable electronics, the continued rise of artificial intelligence, machine learning, cloud and edge computing, autonomous and new energy system vehicles, the Internet of Things specific requirements and quantum developments. Each of these brings with them new functional and cost-performance requirements, affecting design and manufacturing processes, and new material demands.

Based on these factors and themes, this study has identified some market potential opportunities which could be suited to Australia including:

- 5G/6G (particularly in mmwave),
- long-range-low-power wireless (particularly in IoT),
- Aerospace based applications (particularly communications, sensing and radar), and
- Photonics (particularly single photon sources and detectors, and integrated photonics).

There are many other niche or competitive market opportunities where Australian firms, organisations or individuals could make valuable contributions, achieve impact and capture value. Given Australia’s capabilities in quantum computing and sensing, and how that market is developing, as well as developments in materials science and processing, and downstream Assembly, Packaging and Test (APT) automation, Australia has a broad range of opportunities it could pursue (notwithstanding considerable barriers to entry and competency areas to develop).

3.4.2 General Australian advantages

During consultations, some stakeholders raised broader advantages Australia has in increasing its participation in the semiconductor value chain. However, different stakeholders had different views as to the extent to which these broader advantages existed, were generally applicable or were meaningfully impactful in their potential to increase participation. These advantages included:

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[28] For example, 10 years ago, there were 130 publicly traded semiconductor firms globally—today there are 72.
[29] Australian Government, 2020, *Critical Technology Supply Chain Principles – a call for views*, www.homeaffairs.gov.au/reports-and-pubs/files/critical-technology-supply-chain-principles-discussion-paper.pdf.

Australian lifestyle and values: The COVID-19 pandemic has demonstrated Australia offers advantages in high liveability standards, quality of life, political stability, recognition of democratic values and rule-of-law relative to many of its peers. All of these qualities underpin Australia's appeal as an attractive place to live. These qualities can resonate with skilled migration candidates, perhaps tipping the balance for talent to choose Australia over elsewhere.

Australian technological readiness: Australia has historically demonstrated an impressive appetite for widespread and rapid technology adoption.[30] This early and rapid technology adoption has delivered favourable economic outcomes in some of Australia's key sectors. For example, Australia's agriculture and mining sectors, have displayed consistent productivity increases over many years based on technology uptake and improved practices.

Australian university rankings: Australia rates far above its relative size in international university rankings (in terms of population and number of universities). The rankings rise preceded and has been abetted by a dramatic increase in Australian universities providing education services to a fast growing middle class in Asia. Beyond being a major export industry, this has provided an opportunity to inculcate the future leaders of the Asian region who are formally educated here with a favourable view of, and ongoing relationships with, Australia.

Australian dollar exchange rate: On average, the Australian dollar's historical lower exchange rate compared to the home country currency of MNC's operating here in the semiconductor sector provides a helpful, but not always predictable, benefit. Some stakeholders noted that this 'local discount' helped equalise Australia's otherwise higher wages costs. However, perpetual reliance on comparatively lower exchange rates is a transient advantage. Ultimately, the case for locating and investing in complex semiconductor activities in Australia must be an ability to dollar-for-dollar create comparatively higher value, deliver that value and capture that value.

3.4.3 Capability and capacity building

In formulating and initiating government policy and strategy, at least two dimensions are important to consider:

1. That government initiatives address market-failures and frictions, without crowding out market-led activities or creating unintended consequences, and
2. That strategic investments are made step-wise to create accretive capabilities, assets and knowledge which have additive complementarity, high optionality and transferability.

One finding of this study was that it is too premature for Australia to focus all its semiconductor industry efforts around encouraging an existing international fabricator, for example an Intel or TSMC, to establish a new leading-edge node plant here, without first building up local supporting 'innovation infrastructure' to increase Australia's own absorptive and value-add capacity to maximise domestic spill-overs. Of course, Australia should be supportive of new and enhanced MNC development efforts here – but not with a sole focus.

Making investments which create and sustain Australian access to markets, access to capital, access to skills and expertise, and access to co-ordination and collaboration are among the more enduring, appropriate and broad-based steps for Government and their agencies to take. This is a longer term approach which sets the foundations for meaningful participation in a series of critical global value chains both now and into the future: mining and processing, semiconductors, quantum, and other technology applications more

[30] Austrade, 2018, *Australia tops international tech-readiness ranking,* 20 August 2018, accessed 20 November 2020, www.austrade.gov.au/international/invest/investor-updates/2018/australia-tops-international-tech-readiness-ranking.

generally. It would also support growing entrepreneurial capacity which encompasses the creation, delivery and capture of value, no matter the industry.

In this context, the study's findings included a set of actionable levers to grow the Australian semiconductor sector (Table 2 and Figure 4). These levers underpin a wide range of potential initiatives that, while general in nature, can and should be shaped to the particular dynamics of the semiconductor sector and then to the specific target market within that sector. Appendix 1 outlines the range of potential initiatives.

While a number of the initiatives noted in Figure 4 and in Appendix 1 are best commenced now and ideally in tandem, the larger capital incurring decisions could be made once more market assessment is completed and domestic capability builds and takes shape – thus reducing aspects of 'risk' around these larger outlays (Figure 5). A first important step is to build, systematise and disseminate an Australian capability around strategic market foresight, otherwise called 'market intelligence'. This capability could be delivered by a Semiconductor Sector Service Bureau, one of the proposed initiatives, and discussed in further detail below.

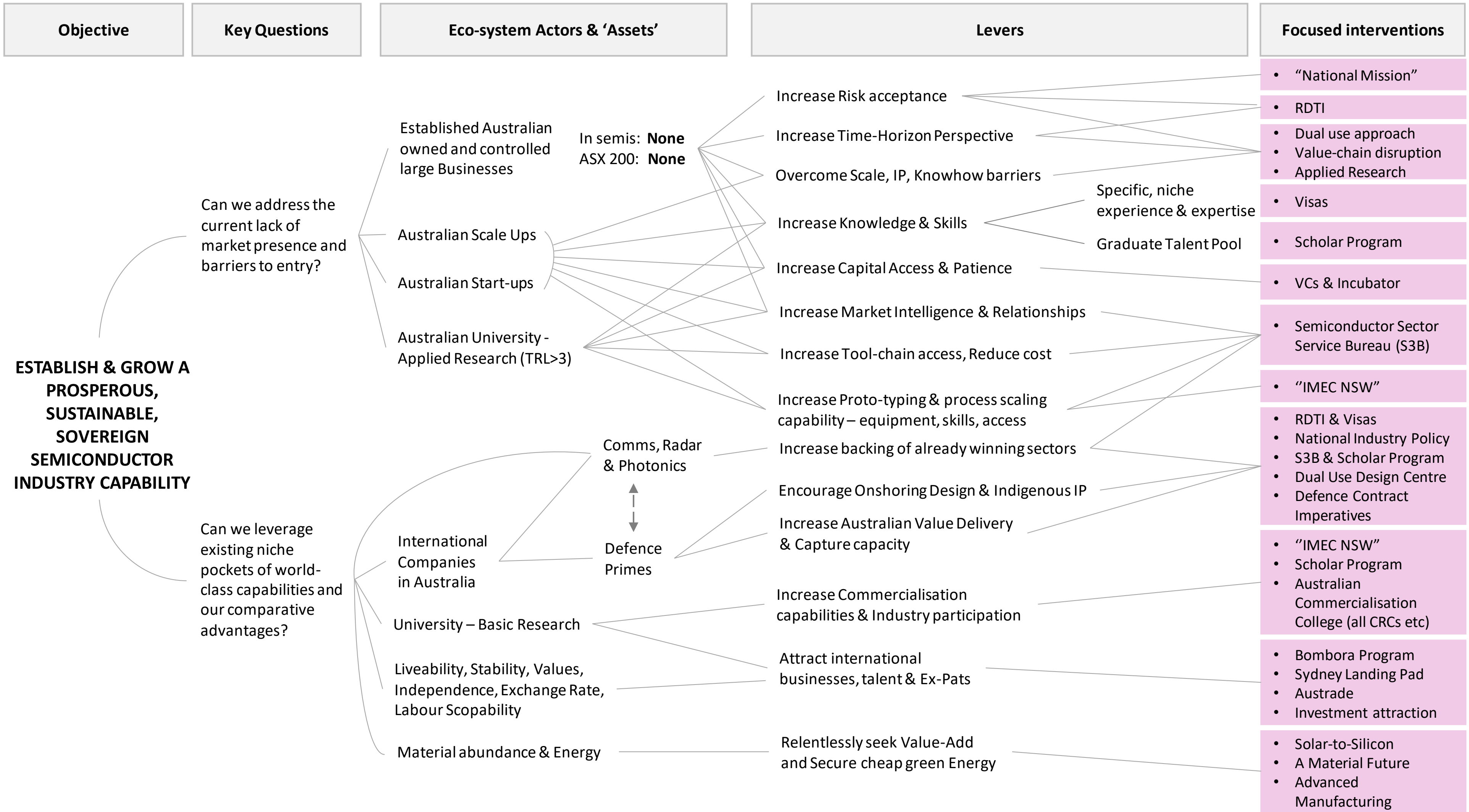

Figure 4: Australia's semiconductor sector levers and potential interventions

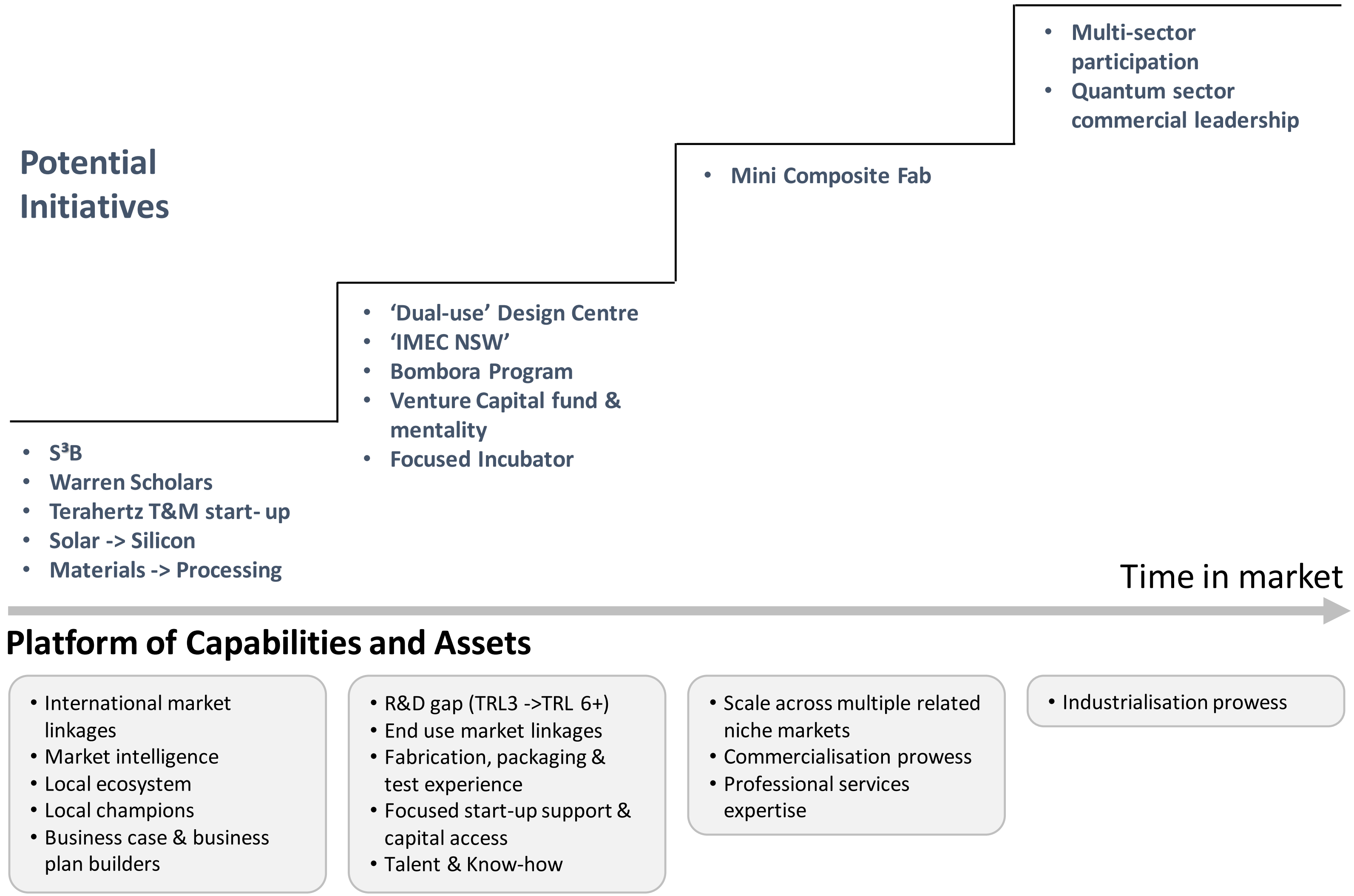

Figure 5: Staircasing capability building and assets in Australia's semiconductor sector

3.4.4 Semiconductor Sector Service Bureau

The Semiconductor Sector Service Bureau ('the S^3B') is one of the key potential initiatives identified in this study, as it is a precursor to the implementation and efficacy of many of the other potential initiatives. The S^3B, would play a key 'hub' role within the overall set of possible semiconductor sector initiatives. It would enhance the capability, market connectedness and competitiveness of Australia's semiconductor sector by providing independent, relevant, effective and cost-effective services to the sector. The S^3B would cover all stages of the global semiconductor value chain: from significant intermediate and end-markets for semiconductors, as well as assisting Australian organisations to more meaningfully participate in parts of the core semiconductor value chain including materials, design, IP, and fabrication.

The S^3B is intended to address a number of market frictions and failures which curtail the ability of NSW and Australia to compete in the global semiconductor markets. In particular, the S^3B would focus on three areas of need:

1. Provide **brokering services** to Australian semiconductor 'fabless' design firms, startups and scaleups, industry-linked Public Sector Funded Institute (PSFI) research organisations and universities to access the most appropriate semiconductor fabrication, packaging, assembly and test facilities globally, on attractive commercial terms.
2. Provide global semiconductor **market intelligence and linkages** to better guide Australian innovation and entrepreneurial endeavours (including startups, academic prototyping, industry commercialisation and government policy) in the semiconductor sector.
3. Foster and enable a more connected and market-aware semiconductor **ecosystem**, including government, defence, research organisations and existing and new businesses (both Australian and internationally domiciled).

3.4.4.1 Brokering services

During consultations a commonly raised issue for startups was the challenge of how to identify, select, engage and manage out-sourced fabrication for a designed ASIC. These activities are often critical from even the earliest stages of chip design, as certain fabrication suppliers and processes have chip design optimisation implications which should be accounted for from the beginning of chip architecture design. These activities are highly demanding in terms of dollars-at-risk and time taxing, but are really only necessary the once. Further, in the absence of an existing local network – where these experiences can be shared – every firm goes through this learning process anew. While this learning process may have inherent value, it could be much accelerated and undertaken at considerably lower cost and with lower overall project risks.

The primary existing fabrication choices for 'standard' integrated circuit, discrete and MEMs fabrication include:[31]

- TSMC
- Global Foundries
- Samsung
- MOSIS
- Europractice
- Semefab
- IQE
- Skywater
- CMC
- eSilicon

Each fabrication vendor has between one and 14 distinct fabrication facilities, with multiple set-ups possible for each facility. Facilities range in node sizes, available processes and equipment maturity, price, demand and scheduling (affecting start and turn-around time). Even for the very largest fabricators such as TSMC, startups and research projects are often

[31] An indicative, non-exhaustive list as at August 2020.

‘competing’ with much larger fabless companies (such as Qualcomm, Broadcom, even Intel now) for space, time and attention. TSMC, like all fabs, evaluate each project even at the earliest stages for relationship potential to TSMC going forward. Channelling as many Australian projects through a professional yet public service ‘broker’ consolidates the collective relationship potential with fabs, lifting each and every Australian project’s ranking.

The S^3B would also provide an experienced eye over the commercial terms associated with the brokered arrangement. Providing feedback and guidance (not legal advice) to the Australian based projects is an immediate value-add uplift. Over time this brings a ‘best practice’ set of learnings to the S^3B which each subsequent project can avail themselves of.

It is important to note that a number of Australian semiconductor design service providers do list ‘foundry services’ as part of their offering. By this they mean a cut-down version of ‘foundry brokering’. In each case, these local suppliers maintain a limited set of foundry relationships, in part due to the close relationship that a particular fab has with the specific design skills and device familiarity that each local firm respectively offers. The S^3B would definitely not provide design skills. Indeed, the S^3B would, as the ecosystem expands, be driving increased business to these local firms for their design services. The channelling of fabrication brokering services for the vast majority of Australian based projects via the S^3B to all possible global fabrication facilities will promote project ‘best fit’ on an overall basis, rather than separate, limited and forced choices.

3.4.4.2 Market intelligence and linkages

The S^3B proposes to develop a strategic and functional market intelligence capability, with the specific sector of focus being the semiconductor sector.

Many countries have national coordination bodies, ‘knowledge foresight’ exercises and accumulating market knowledge and relationship programs to guide policy priorities and strategic direction which transcend and outlast any single firm, big or small.[32] The global market knowledge collected and assessed is not just statistical, at a ‘macro-market’ level, but rather it is granular at the level of individual markets, technology development trends, competitor level assessments, and specific business environmental conditions affecting present and future dimensions of competition.

The major function of such information, studies and assessments, is to “awaken firms to emerging trends and problems, and cajole them into responding. Companies are free to respond in any way they choose. By widely disseminating such studies in industry, however, firms are put on notice that their (local) competitor have (also) seen them. This stimulates added internal study and response”.[33] Increasingly this type of foresight capability is seen as a critical competitive and comparative advantage for nations, firms and individuals.[34]

The intended market intelligence function of S^3B also stretches to ‘linkages’. Linkages, in this sense, refers to an initially quite narrowly defined role to bring the global end-‘customer’, as close to the Australian based researcher, startup, organisation or firm as possible in the early validation stages of value proposition and project or product development conception. Critical to establishing the desirability and viability of a semiconductor business endeavour are the on-going customer and linkages to validate key assumptions about what it is that a

[32] Examples include the Industrial Technology Research Institute (ITRI) in Taiwan, the Research, Innovation and Enterprise Council in Singapore, along with A-STAR, Presidential Advisory Council on Science & Technology in South Korea, The Shanghai Industry Technology & Research Institute (SITRI) in China, Vinnova in Sweden, the US President’s Council of Advisers on Science and Technology, and the Canadian Science, Technology and Innovation Council.
[33] Porter, M.E. 1990, *The competitive advantage of nations.*
[34] Grove, A.S. 1996, *Only the Paranoid Survive: How to exploit the crisis points that challenge every company and career*. Christensen, C.M., Anthony, S.D. and Roth, E.A. 2004, *Seeing what’s next: using the theories of innovation to predict industry change*. McGrath, R. 2019, *Seeing Around Corners*.

market needs and values. These understandings are foundational elements to effective commercialisation practice.

The S^3B will not provide active incubation and startup hub-type services, such as those existing deep-tech facilities like Cicada Innovations already offer. The S^3B services will be complementary to the skill enablement and business development focus of these organisations, by providing market intelligence for semiconductor related endeavours or formation opportunities to hone strategies, customer-led discovery, value-proposition and device/design cost and performance requirements.

3.4.4.3 Eco-system development and enablement

Ecosystems and clusters are much cited as a key foundation for prolonged industry success at a national and regional level. Currently there is no representative, coordinating and collaborating catalyst in Australia for the semiconductor sector. The S^3B can initiate that role and begin to create an ecosystem for demand and supply of opportunities, talent, enterprise and local investment. It would provide introductions between research teams and industry partners and early stage commercialisation skill sets (in IP, legal, finance, marketing, sales, venture capital, recruiting). The S^3B would also develop and share relevant analysis of industry and market 'mapping' in public forums – such as meet ups – as well as through discrete introductions between organisations and people. This will be especially so, by highlighting critical issues that are common to all participants in a developing ecosystem, galvanising the community, and advocating and lobbying publicly (at times) on the ecosystem's behalf to demonstrate whole-hearted leadership.

In enabling the semiconductor ecosystem, the S^3B could also provide:

- **Visa assessment assistance:** the S^3B could assist governments (State and Federal) assess the eligibility and merit of visa requests in the semiconductor sector to promote more timely assessment and access to skills at a pace commensurate with their international peers.
- **International standards representation:** As with most industries, increasingly global standards set key parameters for the basis of competition within the semiconductor sector and its many markets. Their influence can be greater than the effort that goes into their construction. Although typically formulated to increase efficiencies and integration possibilities within the fabrication process, they impact end-use markets, device design and the equipment, tools and materials parts of the value chain. Moreover, the standard setting process is a valuable networking and market intelligence opportunity.

4 CONCLUSION

The semiconductor industry has been an engine for economic growth over the last 60 years and promises to have a continued out-sized contribution to global prosperity. Such benefits, however, have not been evenly distributed, and will not be distributed evenly in the future: early and smart adopters have benefited hugely, and producers of semiconductor sector-related technology have benefited far more than adopters.

This study has identified challenges and opportunities for the semiconductor sector in Australia, as well as a range of potential initiatives which could accelerate growth and participation in this sector (Appendix 1). Working collaboratively around a vital mission, NSW and Australia can join those countries which have developed capabilities, infrastructure and strategies to maximise the creation, delivery and capturing of value around the semiconductor and related sector value chains (Figure 6). Success in this sector could deliver significant economic prosperity benefits for NSW and Australia, both in establishing a new domestic high-tech industry, as well as in delivering spill-over productivity, cost and technology benefits to other sectors.

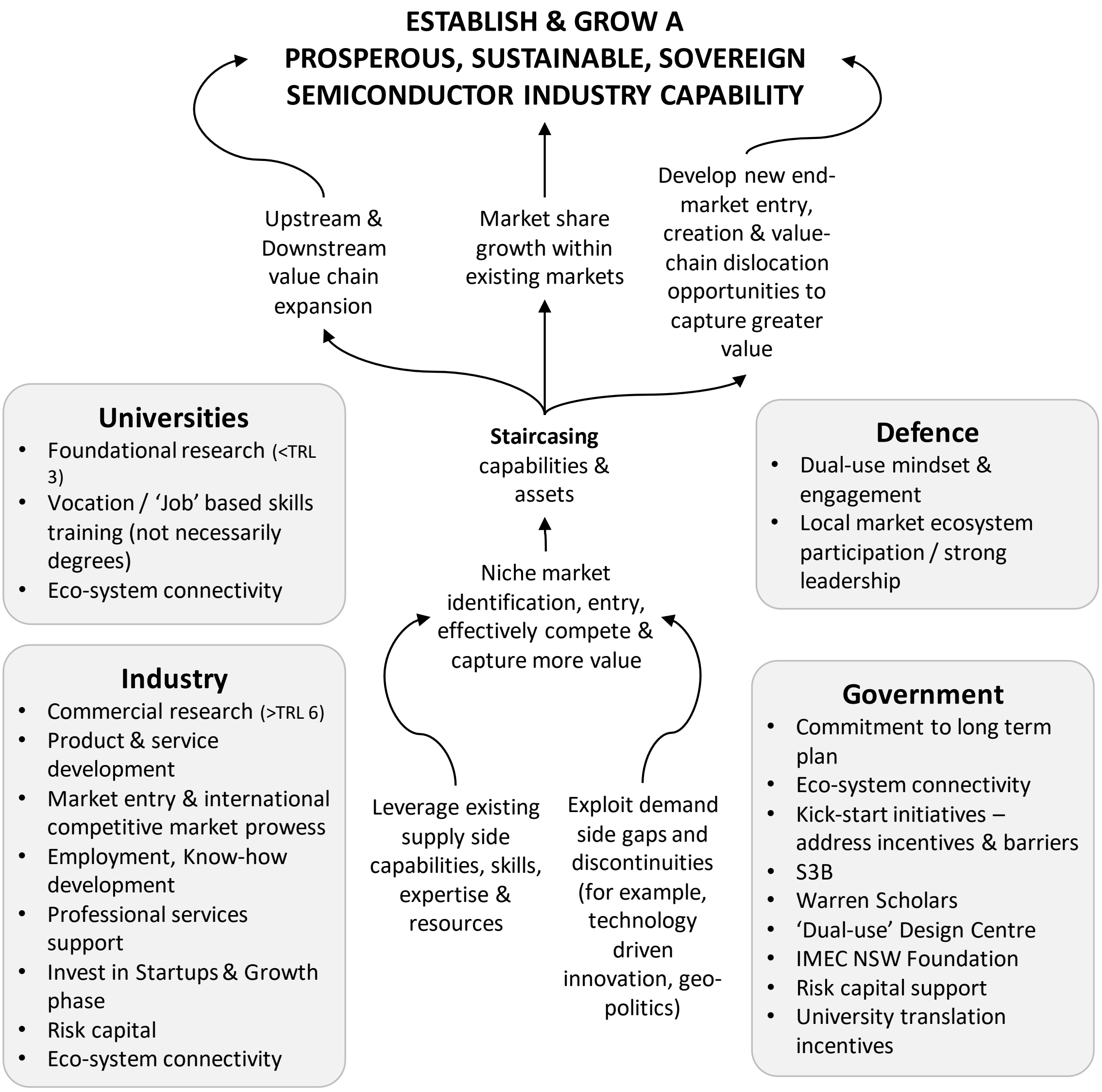

Figure 6: Pathways to growing the Australian semiconductor sector

5 ACRONYMS AND ABBREVIATIONS

Acronym	Definition
5G/6G	Fifth Generation wireless technology / Sixth Generation wireless technology
A$	Australian Dollars
ADF	Australian Defence Force
AI	Artificial Intelligence
AMD	Advanced Micro Devices
ANFF	Australian National Fabrication Facility
ANSTO	Australia Nuclear Science and Technology Organisation
APT	Assembly, Packaging and Test
ASIC	Application Specific Integrated Circuit
ASX	Australian Stock Exchange
B	Billions
CASG	Capability Attainment and Sustainment Group
Comms	Communications (data- or tele-communications)
CMOS	Complementary Metal-Oxide Semiconductor
CRC	Co-Operative Research Centre
CSIRO	Commonwealth Scientific and Industry Research Organisation
DMO	Defence Materiel Organisation
Defence Prime	Refers to one or more of the Defence sector Prime contractors with prominence in the Australia: BAE, Boeing, Lockheed Martin, Northrop Grumman, Raytheon, Thales
DSP	Digital Signal Processor
ECB	Electronic Contract Manufacturer
ECI	Economic Complexity Index
EU	European Union
Ex-pats	Ex-patriots
Fab	Fabrication (plant or facility)
Fintech	Financial technology
FPGA	Field Programmable Gate Array
GaN	Gallium Nitride
GaO	Gallium Oxide
GDP	Gross Domestic Product
GPS	Global Positioning System
IDM	Integrated Device Manufacturer
IMEC	Interuniversity MicroElectronics Center (research institution, Leuven, Belgium)
I/C	Integrated Circuit
InP	Indium Phosphide
IP	Intellectual Property
IOT	Internet of Things
M	Millions
Medtech	Medical technology
MEMS	Micro-electromechanical System
MIT	Massachusetts Institute of Technology
MITI	Japan's Ministry of International Trade and Industry
ML	Machine Learning
mmwave	Millimetre Wave
NSW	New South Wales
OCSE	Office of the NSW Chief Scientist & Engineer
OSAT	Out-Sourced Assembly & Test
PCB	Printed Circuit Board
PFRI	Publicly Funded Research Institutes
PIC	Photonic Integrated Sensor
Quant	Quantum
RF	Radio Frequency

Acronym	Definition
ReRAM	Resistive Random Access Memory
R&D	Research & Development
RDTI	Research & Development Tax Incentive
RISC-V	An open standard instruction set architecture based on established reduced instruction set computer principle
S^3B	Semiconductor Sector Service Bureau
STEM	Science Technology Engineering and Mathematics
T	Trillions
TBD	To Be Determined
TRL	Technology Readiness Level
TSMC	Taiwan Semiconductor Manufacturing Company
US	United States of America
US$	United States of America Dollars
UV	Ultra-Violet
VCs	Venture Capitalists
WiFi	Wireless Fidelity

APPENDIX 1. SUMMARY OF POTENTIAL INITIATIVES

Proposed Initiative	Summary
'National Mission'	**Set national aspirations.** Similar to the US Apollo Program and akin to a 'war time mentality'. The EU have also set research and innovation Missions to solve pressing challenges in society within a certain timeframe and budget. CSIRO recently listed 12 Missions for the Australian context, none of these, however, related to sovereign capacity around national security and economic strength built upon a foundation of more meaningful participation in the semiconductor value chain (#4 agile manufacturing, and #10 critical energy materials, come closest).
'Dual-use Approach'	**Design, produce and sell into both Defence and Commercial markets**. Australia has a small domestic market. Technology development and markets are, however, global scale. Product development needs to be amortised over large volume units or high-value per unit. This requires marketing and sales expertise (including international sales, and great customer requirement elicitation upfront and relationship management throughout). It also requires design and manufacturing methodologies and facilities able to cater to Defence (high value, low units, cutting edge) and Commercial (volume, hence lower cost) end-use applications – from the outset. This means Defence and Industry working together to each other's, and the nation's, benefit. Australia's defence spend is approximately 2% of GDP, or A$43 billion per annum. Australian owned and controlled entities account for a minority of defence technology spending,[35] and, logically, a smaller fraction still represents locally developed, owned and controlled IP exploitable into international defence markets or translated into commercially relevant markets.
Research & Development Tax Incentive modifications	**Tiered premiums for Collaborative R&D under the Research & Development Tax Incentive (RDTI) scheme, especially directed to the semiconductor sector** (for example, +10% for interfirm, +15% for with University basic research, +25% for applied research, +50% semiconductor related). During consultations many Australian based senior managers in the sector stated how vital RDTI was to their early growth and on-going cost arguments for continuing to have operations in Australia. The RDTI is seen as an important government assistance component for (i) cash-flow, (ii) mitigating investment risks, (iii) re-balancing comparative labour costs vis-à-vis other countries, and (iv) off-setting the subsidisation benefits some other countries provide their own domestic industry entities.
'Value chain disruption'	**Ever watchful for opportunities that disruption and discontinuity presents.** The existing global semiconductor value chain is complex, the financial returns are cyclical and often favour a 'winner takes most' profile within each step of the value chain. Barriers to entry are very significant. For example, even if the US$12 billion investment the US Government and TSMC propose to spend on the single new fab in Arizona was accessible in the Australian context, also accessing the necessary know-how and IP transfer to establish and operate such a fab would be challenging. Yet, changes, both large and small are happening all the time across the value chain, core technologies, business models, geo-political environment, and regulations. Being alive to these changes can create opportunities for new entrants. The example of Morris Chang founding TSMC highlights the potential gains to from these opportunities.
'Applied research'	**Catalyst programs, rapid commercialisation upskilling.** Australia is highly regarded, in many areas, for its basic research (TRL <3). Rarely, however, does this research cross the 'valley of death' to commercial application. Incentives to academics to give equal time (as a whole, not as individuals) to applied research (process related) ought to be considered. Academic publication and grant biases against older niche technology platforms need to be considered. Commercial market opportunities exist where and when new (market verified) performance requirements are targeted, even on older technology platforms. The valley of death is a common enough issue across all countries and almost all industries. Many countries and regions, such as the EU, are devoting proportionally much more effort and investment towards translational activities such as prototyping, piloting, process engineering, design-for-manufacturing and scaling steps than Australia is.

[35] Australian Defence Magazine's list of the Top 40 Defence contractors reveals that it is dominated by local subsidiaries of foreign owned prime contractors, with only one single Australian supplier of high technology systems on the list (EOS). Australian Defence Magazine, 2020, *Top 40 Defence Contractors/Top 20 SMEs*, www.australiandefence.com.au/adm/past-editions/adm-december-2019/january-2020.

Proposed Initiative	Summary
'Australian Commercialisation College'	**Key skills gap requires professionalisation.** Early career researchers and students should be coached and trained in the basic principles and value of commercialisation; the set of processes and methods to progress invention to innovation through product and service realisation, to deliver and capture the value of research. Whether this training is personally utilised or not, a more thorough appreciation of the objectives, processes and demands of the commercialisation context will inform their individual projects, and filter through their institutions. This could be accomplished, for example, via an accredited virtually delivered course or program in commercialisation, alongside the deep domain specific skills and knowledge that nascent researchers are trained through in their early careers. While there are existing training entities, some international examples, such as the UK Innovate Catalyst Program, present best practice in professional standards and focused practised application of commercialisation.
'Visas'	**Securing global talent.** This was an almost universal refrain during the consultations made during the study from Australian managers in the sector. Two key issue areas are here, with a few more 'root causes' and related issues underlying the problems. First, even if the quality of current graduates is improved, as it should be, there are still, today, large gaps for five-ten+ year experienced integrated circuit design engineers which can't be filled. 457 Visas are seen as taking too long to be reviewed and are often denied. There are steps that can be taken to favour already winning sectors which clearly need the talent to grow and be competitive. To secure global talent in a globally competitive market Australia and Australian based firms also need to address important factors in the possible Visa Holder's consideration to come to Australia: 1. Landing Pads – consideration should be given to meet the Visa Holders relocation costs as a 'grant' to qualifying companies taking the new employee on board. Face-to-face interviews with in-situ tests during the hiring process are also seen as important and difficult to gain funding for. 2. Back-up job options – few people consider a move to a new country where there is not depth in the labour market for their talent in that country. This is part of the virtuous circle of 'success breeding success' and why comprehensive sector based program initiatives – rather than just for individual companies - has merit: it encourages a critical mass of companies, both horizontal and vertical across that sector's value chain, creating a flow of jobs in and between companies in the sector, and in effect providing a safety net for the class of necessary talent. This then underpins talent consideration to either come to Australia and for our students to be encouraged to pursue careers in certain sectors. 3. An attractive education environment for their children – several integrated-circuit designers consulted during this study who originally came to Australia on Visas and are now Australian citizens mentioned that the quality of the K-12 Education their children are receiving in Australia could be improved. Second, is that the quality and training of Australia's young engineering graduates was raised as a concern. Basic understandings of current flows and signal speeds across a wire are lacking; integrated circuit design skills are brushed over in a single ten week course, assuming students even take the course. Very few Professors have worked in industry themselves or have experience in integrated circuit design. What should be a virtuous circle of 'practical knowledge to instruction to practice to more knowledge' is broken in this area. Australia is missing out on a huge educational opportunity and a necessary but insufficient condition for future success.

Proposed Initiative	Summary
''Bombora Program'	**Targeting expatriate talent.** The proposed initiative here is to bring experienced Australian expatriate semiconductor sector talent back to Australia within a strategic context. The first steps are to identify, track and establish relationships with this talent. Further steps include providing incentives to return and a soft-landing for the expatriate and their family's re-entry into Australia. Morris Chang (of TSMC) is a great example of a Taiwanese expatriate being deliberately targeted and incentivised to return to Taiwan – and subsequently founding semiconductor industry leader TSMC. This approach essentially mirrors China's Thousand Talents program.[36] The issue then becomes retention of the talent.[37]
'Sydney Landing Pad'	**A virtual Landing Pad initiative for both Visa holders and Bombora Program recipients.** The landing pad would cover: (i) relocation assistance; (ii) school and spouse assistance; (iii) connections into relevant professional networks; (iv) input into (national) policy development; and (v) involvement in Incubator mentorship & investment.
'Austrade targeting'	**Targeted export market tactical intelligence and recruiting.** Austrade would hugely benefit from industry briefings on Australia's existing semiconductor capabilities and needs, and this knowledge needs to be put into a framework of strategic partnership targets for (i) individual companies and (ii) the sector as a whole to arm Austrade's daily research, analysis and tactical opportunity identification activities.
'Investment Attraction (FDI)'	**Providing relevant agencies with strategic market linkage possibilities.** State based inward investment attraction agencies, similar to Austrade at a national level, need to be armed with the strategic view and be qualifying market linkage possibilities using the early pages of a semiconductor sector 'partnership development playbook'.
'Scholar Program'	**Creating Australia's engineering leaders of tomorrow.** The concept is to nurture a cadre of Australian scholars focused on the semiconductor sector, in a similar vein to the way the Australian Defence Force Academy trains a cohort of officer cadets each year for the mission of protecting Australia's security via military means. The intent is to be generate a similar local 'cache' and aspirational value as the Rhodes Scholarship program does for business and political pursuits. In essence, each year 25-30 fourth year engineering students are selected for Scholarships to a three year program immediately following their undergraduate studies. The first of the three years being study intensive interspersed with work at their sponsoring (semiconductor sector related) employer, the next two years working full-time with their sponsoring employer. The formal course subjects for the year would have a distinct focus on the semiconductor sector, especially the practicalities of chip design and advanced programming. Courses and course modules would include materials and material science, advanced manufacturing, application markets, project management, corporate strategy, commercialisation and marketing, problem solving, and ethics. Currently the best engineering talent is being sucked up by the global consulting firms and investment banks (for example McKinsey, BCG, Bain, Goldman, JPMorgan), the next tier of talent by firms such as Deloitte, PwC, KPMG, E&Y and Australia's commercial banks and a few handfuls of industrial companies. Some of the brightest go to the local offices of big tech – Google and Amazon, for example – but no semiconductor design work is done by these firms in Australia. Many other high achieving engineering international students return to their home countries. A number of consultations with small but successful Australian operators in the semiconductor sector stated that they are starved of good local engineering talent. In their view they cannot compete with the consulting firms and banks, which have their structured rotational graduate programs. The consultations revealed a few companies (MNCs) who were 'exceptions to the rule' and able to attract local talent they were more than happy with. They put this down to their brand being longstanding household names in the sector.

[36] Hill, K. 2018, *"US fears attempts by Chinese chipmakers to grab top talent,"* Financial Times, 2 November 2018, accessed 10 December 2020, www.ft.com/content/eb145d60-dda7-11e8-9f04-38d397e6661c.

[37] Sharma, Y. 2013, *"China's Effort to Recruit Top Academic Talent Faces Hurdles,"* The Chronicle of Higher Education, 28 May 2013, www.chronicle.com/article/Chinas-Effort-To-Recruit-Top/139485.

Proposed Initiative	Summary
'VC & Incubator' (Venture Capital firms and Incubators)	**Seeding and nurturing the next wave of technology.** Access to early stage and growth capital is seen as a real inhibitor for entrepreneurs considering startups in the semiconductor sector. Capital is important because it typically takes a three to five year (probably a forty person year) engineering effort to get a designed semiconductor chip 'product' to market and begin making any kind of initial revenues – assuming the underpinning science and underlying market need is solid and that the chip works first time. This contrasts sharply to Application development, which can take as little as a couple of software developers and six months, with the Application popped onto the cloud to launch. By the time of the semiconductor firm's first tape-out (the process of turning the full Electronic Design Automation design into the physical chip), a typical semiconductor project will cost \$5m-\$15m and upwards. As a rule, most Venture Capital firms do not like these numbers, least of all Australian Venture Capital firms with limited capital resources themselves. Experienced investors acknowledge that this sector needs at least one sector and/or value chain focused fund. The Limited Partner investors into such Venture Capital funds need to know the risk and likely pay-off profiles of the funds they are investing into. Further, such a fund or funds need General Partners operating the fund who have direct semiconductor sector industry 'round trip' management experience. General Partners with such experience are difficult to come by when the full-cycle is broken. Notably, with the CSIRO sponsored Main Sequence Ventures fund broadly targeting 'deep-tech' early-stage investments there have been a number of investments made into startups pursuing semiconductor design efforts as a significant aspect of their technology and business development. Arguably, this evidences the availability of potential startup supply opportunities within Australia, which could be expanded upon and accelerated with higher levels of funding even more focused on the semiconductor sector and a diversity of Venture Capital firms with semiconductor sector related experience. It is also notable that the Australian Government was a foundational investor into the initial CSIRO sponsored Main Sequence Ventures managed fund. This demonstrates the availability of this 'lever' to be used by governments as one means to address translatable research funding and stimulate innovation in Australia via professionally managed early stage funding vehicles. A semiconductor sector Incubator was also mentioned during the consultation cycle conducted during this study. It was observed that the economics, the skills, and the value chain connections are significantly different for the semiconductor sector – even if the lived experience and stress for the entrepreneurs is similar to fintech, software or med-tech start-ups. Incubators provide a critical mass of shared learnings and opportunities to learn - the daily beating-heart benefits of an eco-system.
'Semiconductor Sector Service Bureau (S^3B)'	**Refer to section 3.4.4 above.**

Proposed Initiative	Summary
'IMEC NSW'	**Bridging from Basic to Applied Research to Industrialisation.** The consultation process provided mixed 'evidence' on the need for an Interuniversity Microelectronics Centre (IMEC) styled presence in Australia. The supply-side economics would also presently be difficult to put together. • The more mature Australian organisations in the semiconductor sector consulted, as characterised by the experience levels (and often the geographic origins) of the founders and key staff, find working with IMEC and other similar specialised proto-type facilities relatively straightforward. In part, this is because these organisations' expectations are well set – it takes eight to twelve weeks for turn-around on the prototype chip fabrication, the process used will not necessarily be perfect, and the cost is high. • Smaller, and less mature, Australian companies (such as startups and academic research driven projects) find the prototype fabrication exercise daunting, draining, prolonged and expensive. They would welcome a local IMEC facility. • It has been noted that a local IMEC-style presence, and even a production level fab, would probably allow for those subtle but important tweaks to a process to occur which otherwise would not be entertained by fab operators in arms-length arrangements. Such tweaks can be important to meet performance requirements – and hence differentiation – of the intended end use of the chip in a device. It is difficult to nurture these flexible relationships from afar. There are also the country and regional prioritisation and competitive elements at play. • Semiconductor chips typically go through 400 different process steps as they are made. At each major group of steps there are many process types to choose from, embodied into many hundreds of pieces of very expensive equipment. The total Australian National Fabrication Facility (ANFF) asset pool relevant to semiconductors barely scratches the surface of the chip process market – even for micro and nano- prototype fabrication purposes. By way of comparison in 2018 the total R&D and capital expenditure by US semiconductor firms alone was US$71.4B[38], in one year. • Maintaining the utilisation of a process and fabrication facility is challenging. While IMEC proudly states that each 'Flemish government Euro' invested into IMEC produces an 8x multiple return, the actual utilisation of facilities is difficult to commercially manage. IMEC draws upon the whole of the EU and globally, including from Australia, for its business. A similar facility in Australia would need to also draw business from a much larger market than what Australia alone offers. • As a first-pass, Australia would need to have a facility, niche and novel enough but with demand-growth potential, that has sufficient scale to provide attractive (globally competitive) economics, to attract international business. There is potential to attract demand from Five Eyes partners to a Trusted Foundry for specific dual use devices. • Some strategic 'partnering or joint venturing with an organisation like IMEC (or a commercial entity) could aid the transfer of IP and expertise to Australia. In any event, being better at winning, delivering and retaining business, are necessary executables for an Australian fabrication facility. These are all areas Australian organisations would need to improve upon, not just the facility itself.

[38] Semiconductor Industry Association, 2019, *2019 Factbook*.

Proposed Initiative	Summary
'Dual Use Design Centre'	**Inwardly, making the most of our national expenditures in a small domestic market**. Dual Use means Defence and commercial markets in terms of end-use applications and markets; however, a Design Centre should cater to Defence, industry, university and government value-add objectives. Design means an (initial) focus on Integrated Circuit (chip) design on a Fabless basis. Target areas might be mmwave, terra-hertz and/or phased array radar. Centre means a collaborative facility, potentially underpinned by a consortium of Defence Primes prepared to bring a 'pre-competitive' mind set to IP Block design for different chip platform targets. Industry entities could partner with a Design Centre Commercialisation Pty Ltd to commercialise the IP into commercial markets, as distinct from Defence markets. The design, management and operation of a Design Centre would likely also follow a 'JV style arrangement' with an experienced co-design facilitator and operator working across defence and commercial markets. Also likely is that the Dual Use Design Centre would have a focus, but not exclusively, around composite materials, especially those on the Gallium Nitride (GaN) and Gallium Oxide (GaO) platforms. These platforms are also of interest to the Defence Primes, match well with existing Australian strengths (RF and radar),and have strong commercial market growth characteristics in areas such as telecommunications, power management and autonomous vehicles. Once a Design Centre is bedded down, and market dynamics allowing, Australia is much better placed to then consider the business and strategic cases for a niche composite fabrication facility, with an objective of attaining US Department of Defence Trusted Foundry Program status.[39]
'Defence Contract Imperatives'	**Outwardly, making the most of our national expenditures and IP creation.** Defence Prime contractors are the primary commercial organisations contracting directly with Australia's Department of Defence Capability Attainment and Sustainment Group (CASG) for the vast majority of Australia's complex defence procurements. The Defence Primes have an important, vital and highly influential role in Australia's present and future military readiness. As MNCs, they will act to the letter of their agreements and national obligations. The Defence Primes do not feel obliged to, nor are their primary business model and business objectives necessarily disposed to, willingly nurture Australian IP creation and control in the semiconductor sector – even if there are multiples of cost involved in doing the same design work themselves in the US (or elsewhere) as opposed to an Australian option even for an Australian Defence contract. There is considerable room for government 'massaging' on this point. Australian content requirements could be ratcheted to include Australian semiconductor chip cores, IP and design content requirements and then, in time, fabrication. Many other countries, certainly the US, regard domestic capability in these areas as fundamental to their national defence.

[39] The US Department of Defence and the National Security Agency (NSA) began the Trusted Foundry Program in 2004.

Proposed Initiative	Summary
'Solar to Silicon'	**The path to Green Energy.** There is a confluence and intersection of rapid development and growth in both the solar energy and silica markets from which Australia could be a significant beneficiary. Silica (silicon dioxide, SiO_2) occurs as the mineral quartz, a major constituent in many igneous and sedimentary rocks. While silica sand and silicon from quartz are processed into various grades for use in concrete additives, ceramics and glass, such as that used in bottles and windows, taking a position in the high grade silicon and silicon compounds required for silicones, silanes, fibre optic cable, UV lights, solar cells and ultra-high purity silicon metal for semiconductor wafers would be a clear and meaningful value-added step. The global silica sand market has grown at about 7.8% per year since 2011, reaching $US8 billion in 2019 and is forecast to grow at 5.8% per year over the next five years,[40] and silica prices are currently at or near an all-time high. A number of challenges require co-ordinated effort to execute on this potential for Australia: • Present international ownership, control and operation of existing Australian based sources of silica, • Lack of local know-how to economically refine and process silica into higher grade products at scale, and • Ability to win and retain downstream customers for refined products. Traditionally the Australian silica market has been dominated by Japanese trading houses operating as private Australian companies and supplying the South East Asian markets.[41] There are, however, a number of predominately Australian owned ASX listed companies qualifying new silica sands reserves. For the most part, currently Australian companies would need to partner with international companies with processing experience to advance their value-add capability. As these international companies protect their own customer bases from further competition such partnerships are not readily forthcoming forcing the Australian companies to negotiate off-take agreements, mostly with East Asia. Australia's basic research expertise in material science could be turned to this topic, and advanced into both applied and industrialised process innovation along economic and environmentally friendly dimensions – of increasing importance to the sector globally. The ability to domestically produce high grade silicon also promotes the possibility of local solar cell production, paving the way for scaled solar farms as a source of cheap green energy. At scale this energy can power the upstream silica processing, and downstream value chain activities including Australia's (future) wafer making and semiconductor fabrication facilities, and also more widely fuel Australia's Advanced Manufacturing base.

[40] IMARC Group, 2020, *Silica Sand Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2020-2025*.

[41] Some of the larger companies currently utilising Australia's high grade silica resources include Mitsubishi (Australia), Taiwan Glass Industry (China and Taiwan), Toyota & Tochu Partnership (Australia, Indonesia, Japan), Xinyi Golden Ruite Quartz Materials (China) and Zhuzhou Kibing (China).

Proposed Initiative	Summary
‘A Material Future’	**Natural endowments, plus basic research capability matches to future opportunities**. Australia is rich in raw material deposits – including rare and critical earth minerals. Some of these rare and critical minerals (such as hafnium, gallium and germanium) are used in high-value semiconductors and other sensitive uses, including, for example, titanium for Pratt & Witney engines in the F-35 fighter jets. Australia also has a strong global reputation in materials science research and materials engineering– especially at the TRL<3 level. In some cases, Australian capability extends into higher readiness levels, such as Thales global centre for ceramics in their global underwater warfare division, which is based in Rydalmere, NSW. Stepping up to the ‘challenge and opportunity’ of value-adding through to end-market participation appears daunting, and is a multi-year, multi capability building task. Establishing significant mineral beneficiation in Australia and then developing into downstream markets in the semiconductor sector, such as composite wafer production, is part of a robust, complex economy. The general factors and levers to enable this to happen have already been highlighted above: talent & know-how, risk acceptance, long-term perspective, capital flows, market intelligence, market access and quite often low cost energy reliability. Apart from those minerals already mentioned above, significant downstream market opportunities are also evident in lithium, graphite, cobalt and indium. Strategically, black phosphorous, erbium, scandium, ytterbium, neodymium and praseodymium are also relevant. Recently the Australian Government established a Critical Minerals Facilitation Office within the Department of Industry, Science, Energy and Resources to coordinate a focused national approach to this sector.[42]
‘Advanced Manufacturing’	**Low-cost clean energy powering an advanced manufacturing base.** The Semiconductor sector is one of the most sophisticated and complex manufacturing linked-process value chains in the world requiring significant energy. The low cost clean energy required for the ‘Solar-to-Silicon’ and ‘A Material Future’ initiatives would also fuel other Advanced Manufacturing endeavours here in Australia.[43] In addition, the further automation of the two most labour intensive steps in the semiconductor value chain (packaging and assembly) greatly assist Australian-based advanced manufacturing engineering and support services, particularly in robotics.

[42] Department of Industry, Science, Energy and Resources, 2020, *Critical Minerals Facilitation Office*, accessed 10 December 2020, www.industry.gov.au/strategies-for-the-future/critical-minerals-facilitation-office.

[43] The Australian Government’s recent released Modern Manufacturing Strategy, *Make it Happen*, emphasises clean energy as a national priority area. The Office of the NSW Chief Scientist & Engineer’s *Decarbonisation Innovation Report*, August 2020, identified and assessed the commercial readiness of a range of low cost renewable generation, storage and grid technologies.

Proposed Initiative	Summary
'5G/6G'	**How Australia secures more trusted 5G equipment supply and becomes a more meaningful participant in that supply chain.** In critical infrastructure, such as 5G, as much sovereign capability as possible is best; second best is working within and between a trusted national group of supply-chain 'partners'. There are hundreds of different 'chips' as components within various parts of 5G systems. There will be a 6G, built upon much technology not yet developed for commercial deployment. This provides a clear line-of-sight for Australia to take a position in 5G now to compete much more assertively (and commercially) in 6G in the late 2020s and 2030s. Australia has a very strong set of design capabilities around certain necessary 5G/6G chip functions. The relevant 5G components are RF filters & amplifiers in the mmwave and terahertz ranges, and power management. Much of Australia's relevant capability is currently employed in MNCs local design centres, which allows for both increased foreign-direct-investment into Australia by these MNCs, as well as new MNCs opening centres in Australia, to utilise and grow capabilities and for possible spin-out startup opportunities. Notable in the present 5G technology sourcing discussion are broader socio-political, national security and economic themes. Nokia and Ericsson are viewed as the main competitors to Huawei as wireless infrastructure suppliers with the longest track-records, 5G technology roadmaps and service capabilities. Korea and Japan are also actively disposed to gaining market share in 5G. Samsung has recently announced a US$6.6 billion 5G infrastructure contract with US wireless service operator Verizon, aided by 5G critical component suppliers such as Qualcomm. On diplomatic, strategic and intelligence fronts there is a deepening of the relationships between existing Five Eyes countries and Japan.[44] NEC are ramping their capabilities to provide 5G infrastructure. Japan has a strong history of advanced communication technologies and products into many end markets. Recently NEC publicly announced they were 'open for business' for supplying 5G equipment into Australia,[45] and have re-enlivened their Wollongong based service and light-R&D facilities.[46] In addition, the Australian House of Representatives Standing Committee on the Arts & Communications reported in May 2020 that 5G, as a fundamental and critical communications infrastructure component, is a security concern to Australia, and that a 5G R&D Innovation Fund ought to be established.[47] NSW is home to 90% of the talent pool that would be able to benefit most (and provide the most benefits to) this initiative.

[44] Panda, A. 2020, *'Is the Time Right for Japan to Become Five Eyes' 'Sixth Eye'?'*, The Diplomat, 15 August 2020, https://thediplomat.com/2020/08/is-the-time-right-for-japan-to-become-five-eyes-sixth-eye.

[45] McIlroy, T. 2020, '*NEC pitches itself as Huawei replacement in 5G rollout',* The Australian Financial Review, 22 June 2020, www.afr.com/politics/federal/nec-pitches-itself-as-huawei-replacement-in-5g-rollout-20200621-p554mo.

[46] Ellis, G. 2019, '*NEC Australia likes Wollongong's advantage and is looking for more office space as it grows'*, The Illawarra Mercury, 14 June 2019, www.illawarramercury.com.au/story/6217130/nec-australia-likes-wollongongs-advantage.

[47] See Recommendation 8 of the Australian House of Representatives Standing Committee on the Arts & Communications, 2020, *The Next Gen Future*.

Proposed Initiative	Summary
'Mini 'Composite' Fab'	**Establishing a composite semiconductor fabrication facility in NSW.** For an Australian Gallium Nitride (GaN), or similar composite material platform such as Gallium oxide (GaO) semiconductor fabrication plant to be feasible would likely require: 1. a joint venture partner or consortium (for example, the Defence Primes) with direct operating experience of a state-of-the-art composite foundry and also to underwrite end-market demand to break-even volumes, 2. a related 'co-design'/'co-creation' capability to assist local Australian firms design for, access and optimise for the particular fabrication process supported by the indigenous facility, in order to grow the supply and diversity of products utilising the plant over time, and 3. an ability to win international business to boost fabrication plant utilisation. This study's consultation process revealed that Australia's semiconductor design capability, while limited in its extent and depth, is world-class in RF, mmwave, photonics and radar. This represents an opportunity to build from as all domains could exploit a GaN platform. Nearly all of the US Defence Primes (such as Raytheon, Northrop Grumman, and BAE) have their own US Department of Defence GaN 'Trusted Foundries' and from time to time these facilities are over-ordered and second-sourcing of fabrication is required. This often occurs to all the Primes at the same time, so they cannot always deal between themselves. A reliable, trusted second source for the Defence Primes is an interesting proposition for Australia to consider. 5G, along with following generations of wireless communications, are expected to rely heavily on GaN based components. So too do key market niches within power electronics, power management, opto-electronics, lasers, LEDs, solar cells, photo diodes, medical equipment and space sector applications. Australia does have experience and capability across the GaN domain with Silanna Semiconductors and BluGlass. Local semiconductor production capacity married to local design (referred to in earlier proposed initiatives, '5G/6G' and 'Dual Use Design Centre') and advanced prototyping facilities ('IMEC NSW'), powered by low-cost clean energy (refer to 'Solar to Silicon') are complementary and important capabilities and assets.
'Terahertz Test & Measurement'	**Early visibility into an emerging end-market supply-chain.** Being an active supplier in the test and measurement market offers an 'insider's view' of where basic and early applied research efforts in a particular sector are being undertaken and allows an opportunity to track worldwide developments at a technical level. Sydney has a strong pool of terahertz related capabilities across research, development and commercial organisations, including early-stage development of test and measurement equipment. This is an emerging subsector worth considering.

APPENDIX 2. REFERENCES FOR MARKET SIZE ESTIMATES

Global Value Chain Segment	Estimated market size (2019)	References
Inputs and Intermediate Processes	US$130 billion	(a) IMARC Group, 2019, *Semiconductor Materials Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2019-2024*, www.researchandmarkets.com/reports/4828708/semiconductor-materials-market-global-industry. (b) SEMI, 2020, *2019 Global semiconductor equipment sales slip 7 percent to $59.8 billion,* 14 April 2020, www.semi.org/en/news-resources/press/2019-global-semiconductor-equipment.
Design IP Blocks Licensing	US$4-10 billion	(a) Clarke, P. 2020, *Synopsys above ARM in IP licensing revenue in 2019*, eeNews, 25 March 2020, www.eenewsanalog.com/news/synopsys-above-arm-ip-licensing-revenue-2019.
Fabless Design	US$100 billion	(b) Markets and Markets, 2020, *Semiconductor Intellectual Property (IP) Market with COVID-19 Impact Analysis by Design IP, IP Core, IP Source, End User, Vertical (Consumer Electronics, Telecom & Data Centers, Automotive, Commercial, Industrial), and Geography - Global Forecast to 2025*, https://www.marketsandmarkets.com/Market-Reports/semiconductor-silicon-intellectual-property-ip-market-651.html. (c) Statista, 2020, *Fabless/system company versus IDM IC sales worldwide 1999-2019*, www.statista.com/statistics/553236/worldwide-fabless-system-company-idm-ic-sales-comparison.
Fabrication (non IDM)	US$42-57 billion	(a) IC Insights, 2020, *Pure-Play Foundry Market On Pace For Strongest Growth Since 2014*, 22 September 2020, www.icinsights.com/news/bulletins/PurePlay-Foundry-Market-On-Pace-For-Strongest-Growth-Since-2014.
Integrated Device Manufacturer (IDM)	US$260 billion	(a) Statista, 2020, *Fabless/system company and integrated device manufacturer (IDM) IC sales worldwide from 1999 to 2019,* *www.statista.com/statistics/553236/worldwide-fabless-system-company-idm-ic-sales-comparison*.
Packaging, Assembly & Test, Integration & Software	US$31 billion	(a) Market Intelligence & Consulting Institute, 2020, *Development of the Global IC Packaging and Testing Industry, 2019 and Beyond*, www.researchandmarkets.com/reports/4904390/development-of-the-global-ic-packaging-and. (b) Coherent Market Insights, 2020, *Semiconductor Assembly And Testing Services Market Is Expected To Exhibit A CAGR Of 4.04% During The Forecast Period (2019-2027)*, 7 February 2020, www.coherentmarketinsights.com/press-release/semiconductor-assembly-and-testing-services-market-2803.
Sales, Distribution, Marketing & Customer Services (chips)	US$420 billion	(a) Semiconductor Industry Association, 2020, *2020 SIA Factbook*.
End-market Equipment, incorporating chips	~US$4 trillion	(a) Oxford Economics estimated that in 2012 the semiconductor industry helps create $7 trillion in global economic activity and is directly responsible for $2.7 trillion in total annual global gross domestic product (GDP). See Oxford Economics, 2013, *Enabling the Hyperconnected Age: The role of semiconductors*, www.semismatter.com/enabling-the-hyperconnected-age-the-role-of-semiconductors. See also Samuels, J. 2012, *Semiconductors and U.S. Economic Growth*.