Lighting a New Path

Global Opportunities for the Photonics Industry in South Australia

November 2022

SOUTH AUSTRALIA

Government of South Australia

Department for Industry, Innovation and Science

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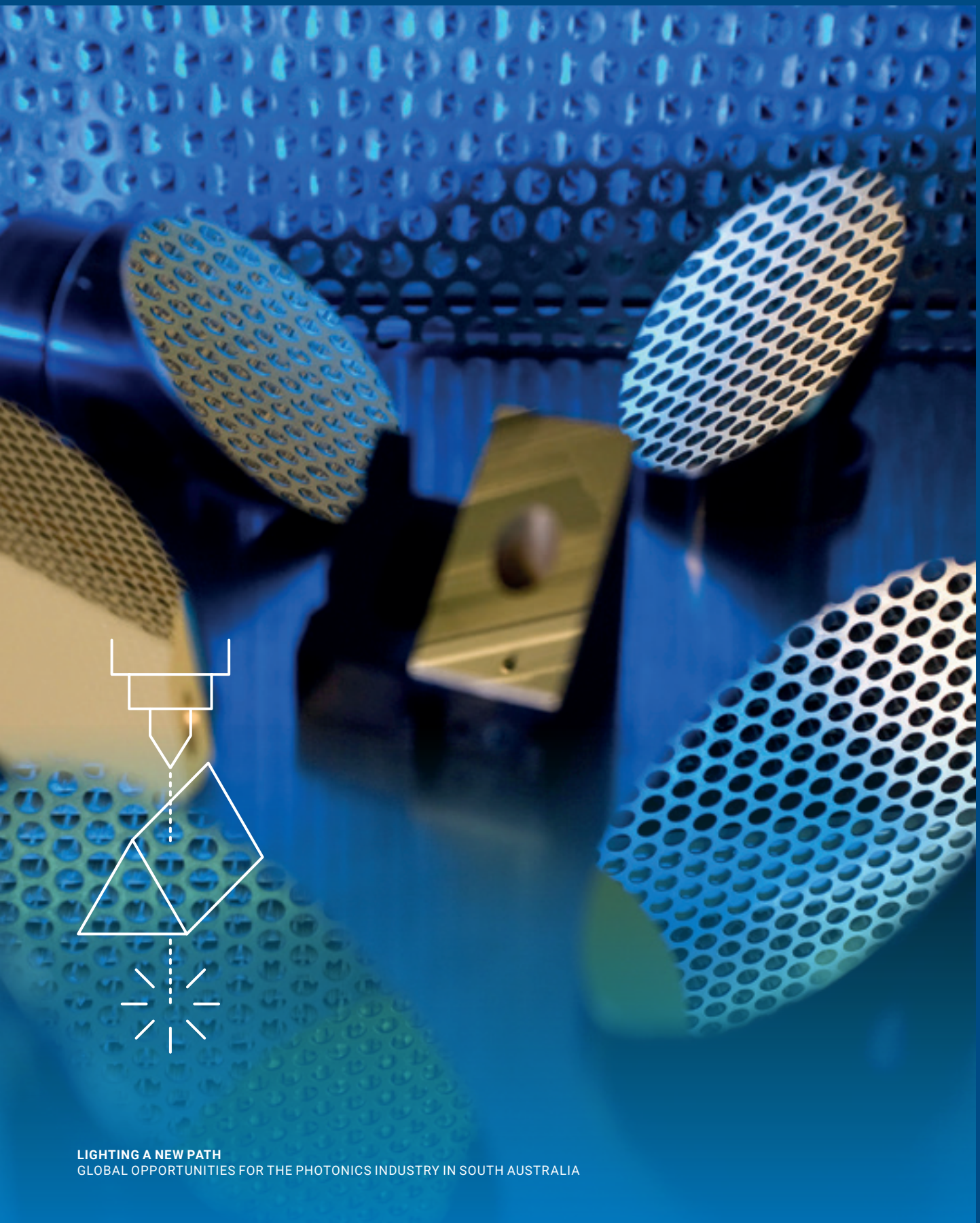
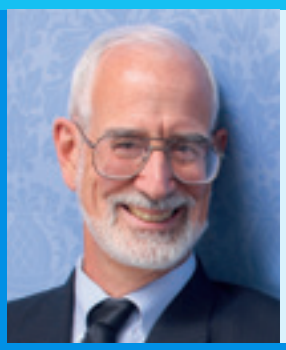


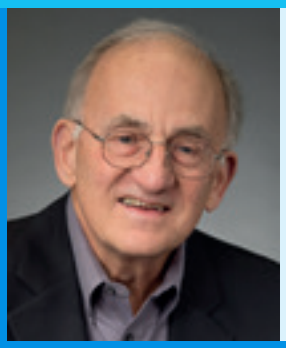
The authors

The South Australian Photonics Roadmap consulting team is led by three professionals with more than 130 years of combined experience in developing optical and photonic products and businesses. All three are active players in the global photonics industry and have worked with a host of small (start-up), medium, and large (multi-billion-dollar) enterprises in contract research, product development, industry standards, company formation and funding, road-mapping, government policy, and acquisitions. This same team conducted the research, analysis and writing of the previous Photonics Roadmap *'Lighting the Way'*, a document prepared and released in 2017.



Dr. Robert A. Lieberman – President Lumoptix LLC

is a member of the US National Academy of Engineering. He began his career at Bell Labs, and has co-founded more than half a dozen photonics companies. He has extensive experience in industry and working in conjunction with government laboratories. He was a founding member of the US National Photonics Initiative, a highly effective advocacy group for photonics in Washington DC, and has served as President of SPIE, the International Society for Optics and Photonics.



Dr. David Krohn – Managing Partner of Light Wave Venture,

a photonics business development firm with more than 125 clients. He began his career working in the glass industry. He developed a fibre optic process at Exxon, which was spun out as EOTec. EOTec was acquired by 3M, where Dr. Krohn became the Chief Executive of 3M's optical fibre business. He has developed numerous books and short courses on photonics-related subjects, and is the author of *Commercialisation Basics for the Photonics Industry*.

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a 15-year-old photonics consulting firm. He began his career at ABB, and has worked for several small/medium enterprises to develop photonic products and business strategies. He has extensive experience in fibre optic sensing technologies, and has consulted for scores of companies on specialty optical fibres and fibre sensing technologies.

Full biographies of all three authors can be found in Appendix A.

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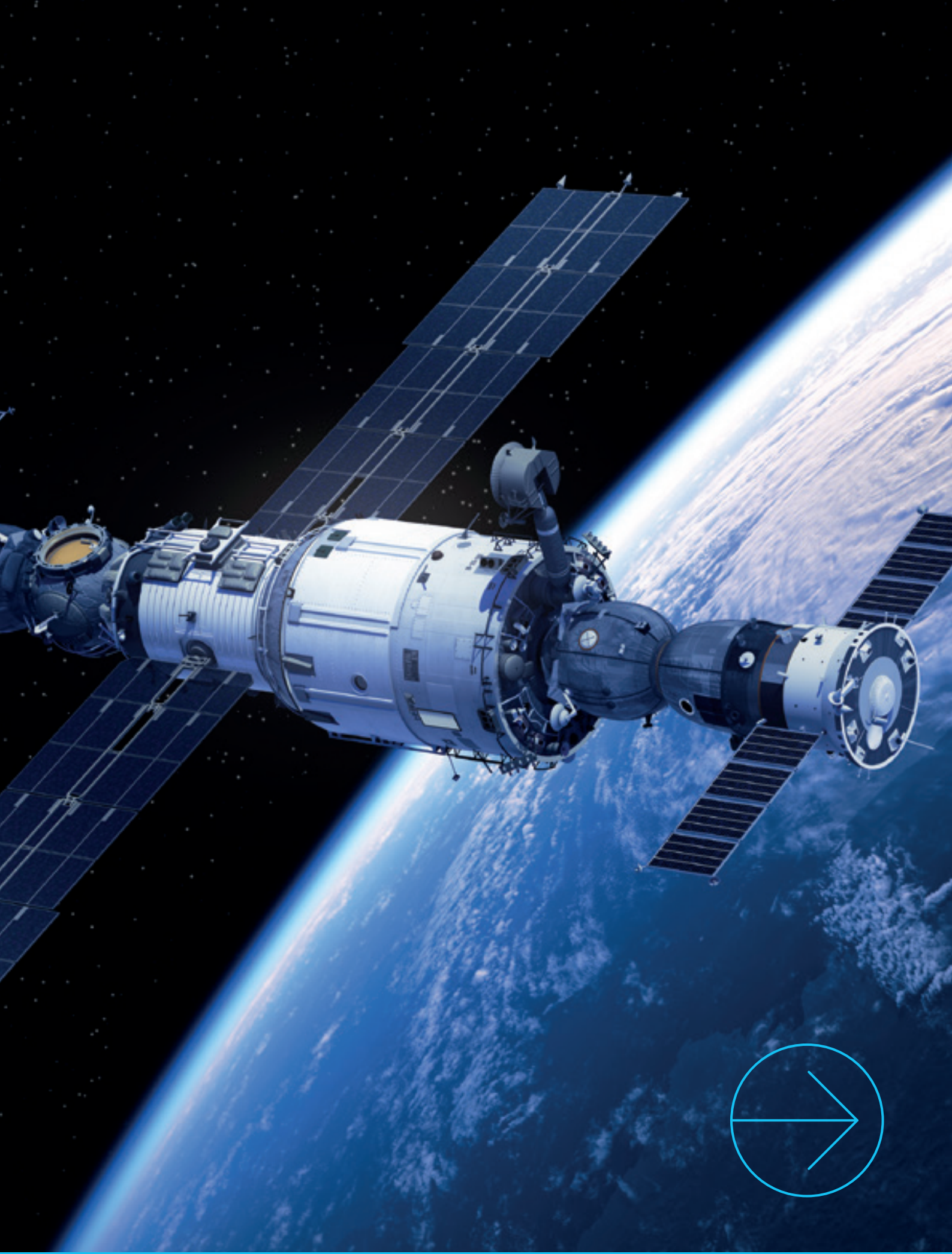


Message from the Deputy Premier

Research and innovation are key drivers of economic transformation, and they are critical to creating and sustaining successful economies.

The South Australian Government is committed to harnessing critical technologies to drive innovation, solve problems and attract investment to our state.

South Australia has an enormous opportunity to become a global leader in one of these critical technologies, which is central not only to a wide variety of industries, but also to the everyday lives of our entire community.

Photonics uses the power of light to create new products, solutions and systems to bring people and data together.

Known as 'the electronics of the 21st century', photonics technology is intrinsic to our society – from microchips to cars, the screens on our electronic devices, and the sensors in public bathrooms right through to advanced aircraft.

The global photonics market is worth AUD$894 billion, and this is expected to grow to $1.34 trillion before the end of the decade.

And the sector is thriving here in South Australia, with our photonics output increasing two-fold to AUD$614 million since the South Australian Government commissioned international experts to develop a roadmap for the industry back in 2016.

With the intervening years seeing new technological developments, as well as the changes brought about by the Covid-19 pandemic, critical technologies have become even more important to the future of our state.

Considering these developments, we asked the team who developed the first report to provide an update on the photonics industry and its four sub-sectors of biophotonics, lasers, optical sensors, and specialty glass and optical fibres, and any new strengths or opportunities for our state.

This updated roadmap reveals that South Australia's expertise in these four key markets has grown even stronger in the last six years, and pleasingly, we're also developing a globally-leading capability in quantum photonics – a new area of photonics that uses ultrasensitive measurements for military, space and geophysics.

This is fantastic news for an industry that is becoming increasingly important to our lives, and it is testament to the incredible industry and research organisations that call South Australia home.

Thank you to the team for their work in providing this update to the photonics industry roadmap for South Australia.

I look forward to continuing to work with businesses and researchers to further grow this exciting and globally important field of technology.

Hon. Susan Close MP
Deputy Premier
Minister for Industry, Innovation and Science

The South Australian Government is committed to harnessing critical technologies to drive innovation, solve problems and attract investment to our state.

Executive summary

South Australia is considered one of the world's best places to live, and the South Australian Government wants to also make it one of the best places to start and grow a business. Within this context, there is already a relevant business sector in South Australia that is high-tech oriented, conducive to innovation, offers substantial market opportunities, and builds on a strong base of existing local capabilities and resources to provide light-enabled products and services – **this is the photonics sector.**

This report is an update to *Lighting the Way*[1], a document prepared in 2016 and released in 2017 that presented the opportunities for the South Australian photonics industry. This new update outlines the new opportunities for the industry which have arisen in the intervening years.

Photonics harnesses the power of light to create new products and solutions for applications in agriculture, communications, healthcare, mining, and defence, among many others. Photonic-enabled systems permeate our society – the networks that bring people and data together, the tools used to fabricate microchips and automobiles, the screens on phones, computers, and televisions, the sensors in everything from advanced aircraft to washrooms – all depend on photonic technologies. Photonics is a USD$600 billion (AUD$894 billion) global market, growing at a compound annual growth rate (CAGR) of 6 per cent. Before the end of the decade, **the photonics industry will represent a USD$900 billion (AUD$1.34 trillion) opportunity**.

In the past six years, employment in the photonics sector in South Australia has grown from 800 to approximately 1,500 jobs, and photonics revenues have grown from an estimated AUD$200 million to AUD$400 million per annum. There is every reason to expect that this growth can accelerate the state's leadership in this field given the unique collection of physical and human assets already residing in the state.

South Australia has maintained its longstanding leadership in Australian fibre optic sensor research. Though nascent attempts at commercialisation are moving slowly, this capability has great potential for near-term economic impact. Early strength in what is now called quantum photonics has become recognised as a core competency, and is the basis for the most rapidly growing photonics company in South Australia, *QuantX*. Products based on unique laser systems, the traditional core of the photonics business community, continue to bring the most commercial photonics revenue into the state, and exciting new developments in specialty glass research and semiconductor sources hold promise of revitalising this mature industry. Biophotonics research, while always strong, has been revitalised with the addition of additional world-class talent and the founding of a new company producing instruments for light-based medical treatment.

1 Lieberman, R., Krohn, D., and Méndez, A. *"Lighting The Way: Global Opportunities for the photonics industry in South Australia"*, South Australian Department of State Development, February 2017.

There are scores of companies and organisations in South Australia that depend on photonics for critical aspects of their operations. Almost without noticing it, businesses that range in size from telecommunications giants stretching fibre optic cables across the Australian and global landscape, to vendors selling glittering novelty items on the street, have – in one way or another – become dependent on photonics, the 'electronics of the 21st century'.

There are five areas of photonics in which South Australian institutions and companies unquestionably excel:

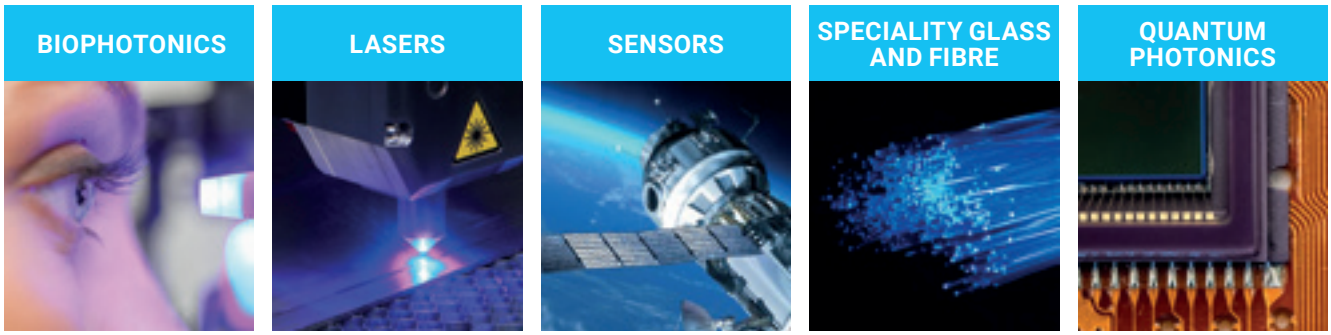
Biophotonics – imaging and diagnostics for biomedicine, agriculture, and environment

Lasers – customised for military, space, biomedical, industrial, and mining applications

Optical sensors – for environment, space, energy, military, infrastructure, and industry markets

Specialty glass and optical fibres – for use in all of the above technologies and markets

Quantum photonics – ultrasensitive measurements for military, space, and geophysics



Each of these core strengths offer attractive commercial opportunities – not only for producing products and services that will materially improve the wellbeing of South Australians, but also afford economic rewards by expanding the reach of existing and emerging businesses into lucrative international markets. Examples include ophthalmological products, remote sensing systems (space-based and terrestrial), high-power fibre lasers, fibre Bragg grating sensors, quantum sensors, and many others.

While by no means exhaustive, this short list illustrates an important point: many photonic technologies and products can use South Australia's success as a springboard to tap larger markets – first by expanding their reach into the rest of the Commonwealth and, ultimately, globally. As noted in *Lighting the Way*, Australia "provides an ideal test market and 'growth chamber'. If a product succeeds in Australia, there is every reason to believe that it will succeed in Europe and the US."

This is particularly true for photonics-based products. Through this well-worn path, with proper direction and support, the South Australian photonics enterprise can become truly international in scope and impact.

01. Introduction

Lumoptix LLC, a consulting company with broad expertise in technical and commercial aspects of optics and photonics, in collaboration with the University of Adelaide and its Institute for Photonics and Advanced Sensing (IPAS), has been engaged by South Australia's Department for Industry, Innovation and Science to deliver an update to the Photonics Industry in South Australia report, which was released in February 2017. The aim of this new and updated report is to provide an update on South Australia's capabilities and opportunities, taking into account technological developments which have occurred over the intervening years.

1.1 Background and motivation

Photonics has been previously identified by South Australia as a key enabling technology and strategic sector on which to focus in fostering the growth of the state's technical and economic base. Photonics is an enabling technology with a broad presence across many applications and industries, and is a global, multi-billion-dollar market. The broad nature of photonics, including the technology and market applications, presents the opportunity to create a platform that allows the technology to be commercialised, generating a financial result that creates positive economic growth, and expands employment in an environment with long term sustainability.

Based on these facts and trends, in 2015 the South Australian Department of State Development (now the Department for Industry, Innovation and Science - DIIS), commissioned this team to research the state of the photonics industry and its associated entrepreneurial ecosystem, and outline where South Australia has globally-leading capabilities and outline international opportunities for businesses in this sector.

Since technical fields can advance and progress quite significantly in the span of only a few years, that original 'footprint' is now re-assessed in this updated report to ensure that any new technical and market developments that occurred since then are taken into full consideration. It also assesses how much South Australia has grown its own ecosystem to support a thriving local photonics industry, taking into consideration Australia's ongoing efforts on the so-called critical technologies - of significant relevance to the country's national security and regional sovereignty, and a major force in driving its economic prosperity.

1.2 Objectives and scope

The primary goal of this report is to provide an updated report for key stakeholders in South Australia to help capitalise on the state's considerable investment in the growing photonics industry, and help grow and develop it further.

Applying the same methodology used to produce the 2017 report, *Lighting the Way: Global Opportunities for the Photonics Industry in South Australia*, this update analyses the current status of photonics science, technology, and the industry in the state, and identifies competitive advantages in niche areas that will make it an internationally recognised centre of photonics excellence. It provides a new analysis of global photonic markets identifies opportunities relevant to the current situation.

As a stand-alone industry, and a key enabler for other critical sectors, photonics can provide significant technological and commercial standpoint benefits to key segments of South Australia's economy, including those encompassed by the national Critical Technologies blueprint.

The specific objectives of this updated report are to:

a. re-assess the capabilities and techno-economic situation for photonics in South Australia by evaluating how much of its associated support ecosystem has changed and improved since 2016, including reviewing the current research, development, and supply chain capabilities in photonics in South Australia
b. provide a foresight analysis of current and future global opportunities which have developed since 2016 in photonics that would be of benefit to South Australia
c. match the capabilities identified in part a) with the opportunities identified in part b) and outline key opportunities for South Australia, including where the state could build new competitive or comparative advantages.

This updated report identifies the technologies, market opportunities, and key customer targets, to maximise the commercialisation of South Australia's photonics industry. The roadmap will also:

- provide an updated analysis of South Australia's current photonics capabilities within research institutions and industry;
- examine whether South Australia still has the potential to be a globally leading centre of excellence in niche areas of photonics; and
- provide an updated understanding of current and future market opportunities and assess whether these match with the identified capabilities.

02. The economic impact of photonics

2.1 Photonics overview

Photonics is the science of light that is at the heart of a myriad of technological innovations. Engineers employ photonics to make advances in manufacturing, quantum computing, communication systems, computers and smart devices, medical devices and imaging, satellite reconnaissance, research, and most of the technologies at the heart of modern society.

Photon engineering - the transmission, manipulation, and detection of light waves and photons - is made up of a range of many different technologies. Semiconductor devices, optical lenses, optical fibres, glasses, thin-film coatings and optoelectronics are all covered by the term, along with newer technologies such as quantum sensing. Photonics (and optics) are prevalent in almost every aspect of today's modern society, from fibre-optic communication systems that deliver voice, data and internet streaming, to the screens in computers and smart devices, to medical imaging and satellite recognisance, to modern car headlights.

In essence, photonics is a versatile and powerful enabling technology that will continue to impact and enhance people's lives around the globe, and create bountiful technical and commercial opportunities for South Australian research institutions and businesses.

2.2 The role of photonics in South Australia's economy

One of the key characteristics of photonics is how pervasive it is across many different products and applications. Photonics features heavily in:

- advanced manufacturing, with high power fibre lasers
- medicine and life sciences, with sensors, lasers and imaging systems
- in telecommunications, with optical fibres and networking equipment
- in defence, with remote sensing and computer vision technologies
- and many more.

Table 2.1 summarises some of the most common applications of photonics and the components associated with each application. Such a range of sectors and products makes photonics an attractive industry to specialise in due to its diversity and usefulness, and a true enabling technology. Furthermore, the breadth and depth of the photonics industry allows it to touch on many, if not all of the technologies identified in Australia's national Critical Technologies blueprint[2].

2 https://www.pmc.gov.au/domestic-policy/critical-technologies-policy-coordination-office
As of October 2022, the Commonwealth Government is currently seeking feedback on how they should update the Critical Technologies list.

Commercial segment	Photonics products
Production technology	Laser materials processing systems Lithography systems (IC, FPD, Mask) Lasers for production technology Objective lenses for wafer steppers
Optical measurement and machine vision	Machine vision systems and components Spectrometers and spectrometer modules Binary sensors Measurement systems for semiconductor industry Measurement systems for optical communications
Solar energy	Solar cells Solar modules
Medical technology and life science	Lenses for eyeglasses and contact lenses Laser systems for medical therapy and cosmetics Microscopes and surgical microscopes Medical imaging systems (only photonics-based systems) Ophthalmic and other in vivo-diagnostic systems Systems for in-vitro-diagnostics Biotech R&D systems
Defence and space photonics	Vision and imaging systems Infrared and night vision systems Ranging systems Munitions/missile guiding systems Military space surveillance systems Avionics displays Image sensors Lasers Directed-energy weapons
Lighting	Lamps, LEDs and OLEDs
Optical communications	Optical networking systems Components for optical networking systems
Optical systems and components	Optical components and optical glass Optical systems ("classical" optical systems) Optical and OE systems and components

Table 2.1
Example applications and segments where photonics is used

Source: *Lighting The Way: A Roadmap for the development of the photonics industry in South Australia*, South Australian Department of State Development, June 2016.

2.3 Economic and social impact of photonics

Photonics is a key driver of technological innovation, and a global economic engine. It delivers direct economic and social benefits to any locality or nation by creating jobs, fostering innovation, and improving the human condition.

The total impact of photonics on the global economy can be best appreciated by considering the number of layers of 'vertical markets', progressing from core components to high value-added products, which would be impossible to manufacture without photonic components, as seen Figure 2.1. The global market for core photonics components and materials was more than USD$300 billion (AUD$447 billion) in 2022, and comprises approximately 4,800 companies in more than 50 countries[3].

Collectively, these companies produce core photonics components and materials, including optical materials, LEDs, lasers, detectors, image detectors, lenses, prisms, optical filters, gratings, fibre optics, and other photonic components. But this is only a fraction of the total value delivered by photonics to the global economy. When *photonic products* (articles whose main purpose is delivering, detecting, or manipulating light) are considered together with core components, the market size grows to USD$600 billion (AUD$894 billion). The true impact of this industry was shown in a comprehensive report that placed the total 2019 market for photonics-enabled products (those that would not exist without photonic components) at more than *two trillion* dollars (*USD$2,000 billion*) (*AUD$2,981 billion*).

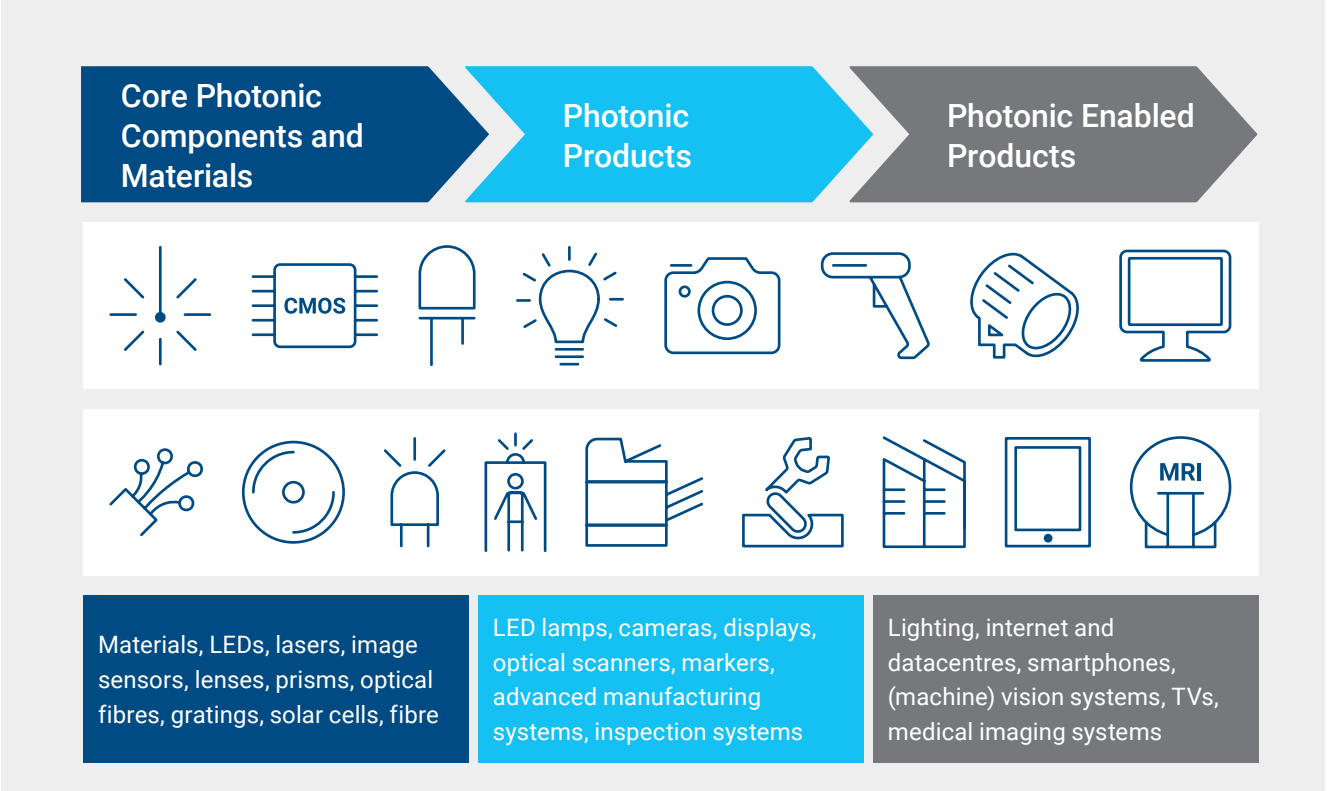


Figure 2.1
Photonics components are the foundation of a global industry of multiple vertical markets offering different photonics-enabled products and services.
Source: *Optics & Photonics Industry Report,* SPIE, Belingham, WA, 2022.

3 *Optics & Photonics Industry Report*, SPIE, Belingham, WA, 2022.

When core photonic components are integrated into subsystems and products whose primary function is to manipulate, measure, or record light, significant added value is provided to the customer; thus the market for photonic products becomes two to three times larger than that for core photonic components and materials. Photonic products may be sold directly to the consumer, or may be incorporated in other products, enabling them to perform advanced functions that again add significant value for the ultimate purchaser. Finally, photonic materials, components, products, and systems provide the critical underpinning for the critical industries on which modern society depends.

The core photonics components industry is also a critical enabler of many other value-added products and services. The combined optical and photonic components, photonic products and subsystems, and photonics-enabled products enable a variety of global businesses. ***If photonic technologies suddenly disappeared or stopped working, the world would lose approximately AUD$140,000,000,000,000 in annual economic output overnight.***

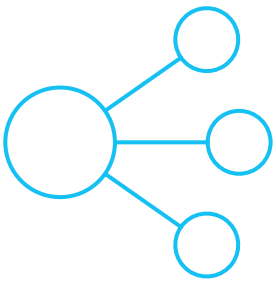
Photonics has a large and direct impact on employment. The core components and photonic product segment of the industry employs approximately 3.7 million people, spread over 50 countries. Small and medium size enterprises (SMEs), account for approximately 80 per cent of the firms in these sectors.

Photonics is also a powerful society-changing tool, with the capability to improve many facets of life. For example, the data centres that form the backbone of the internet (and cloud computing) each contain millions of lasers. Photonics will also be the key technology enabling the development of faster, multi-terabit capacity optical communications at the trans-oceanic, national, metropolitan, and home levels. Advances in new optical fibres, light sources, integrated optic devices ('photonic IC chips') networking equipment, and deployment of FTTX (fibre to the 'X', where X is the curb, home, net, antenna, etc.) technology, are all photonics-based.

With a growing and ageing global population, healthcare needs are becoming more prevalent, and photonics has proven to be an excellent tool for developing new medical sensing, imaging and treatment technologies for bio-medical and life science applications, aiding in the development of more radical and effective systems to diagnose, treat and cure diseases.

Photonics-based imaging and sensing technologies, such as LADAR (laser detection and ranging) and LIDAR (laser imaging detection and ranging), fibre optic sensors and others, are helping make the environment greener by detecting pollutants in the air, soil and water, minimising the impact of resource-recovery operations in the petrochemical and mining industries, and maximising the efficiency of fossil-fuel burning power plants and engines.

Finally, numerous defence applications, notably night vision, laser target designation, optical image acquisition and processing, ground-based and marine sensors, and advanced displays all depend on photonics.



2.4 Photonics and Australia's critical technologies

In 2020, the Australian Government set out to identify current and emerging 'critical technologies', which have the capacity to significantly enhance (or pose risk) to the national interest. Using advanced foresight analysis techniques, a team of experts identified a list of 63 key technologies, further subdivided into seven technology sectors, as shown in Table 2.2.[4]

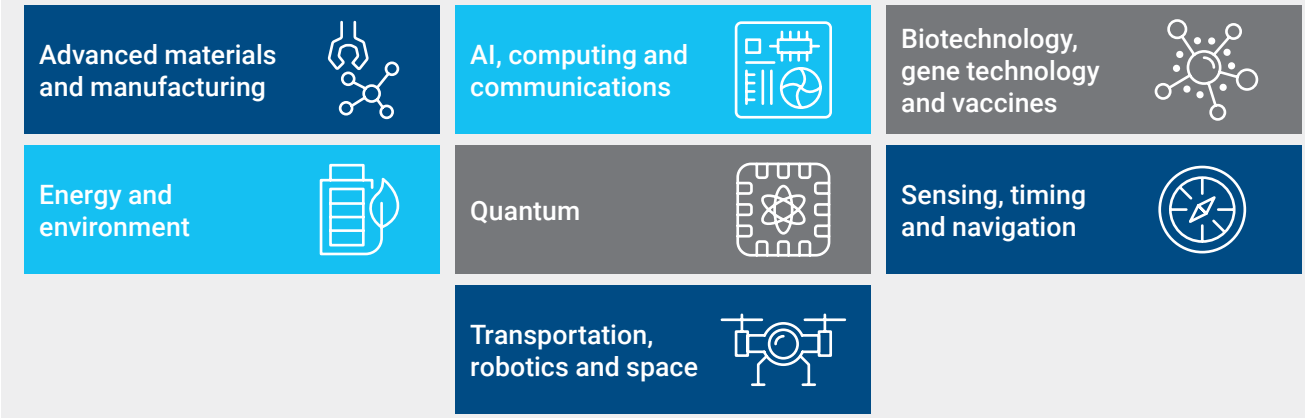


Table 2.2
The seven technology sectors that encompass Australia's 'critical technologies'
Source: Commonwealth of Australia, Department of the Prime Minister and Cabinet, *CTPCO Action Plan*, 2021.

Of these 63 technologies, at least a dozen directly tie to photonics, such as *advanced integrated circuit design and fabrication, advanced optical communications, photovoltaics, quantum communications, quantum sensors, advanced imaging systems, multispectral and hyperspectral imaging sensors, photonic sensors, sonar and acoustic sensors, and others.*

It is expected that adequate investment and development of these critical technologies would be fundamental to Australia's economic prosperity, social cohesion and national security. Critical technologies are enablers to drive economic growth and improve domestic capabilities for defence and national sovereignty. Therefore, given how pervasive photonics is across diverse technologies, it is an extremely valuable techno-economical sector with the intrinsic capability to impact and benefit Australia's critical technologies.

4 https://www.pmc.gov.au/resource-centre/domestic-policy/list-critical-technologies-national-interest

South Australia's established photonics businesses and research institutions will enable the state to develop and commercialise photonics applications in every critical technology area, as demonstrated in Table 2.3.

Critical technologies in the national interest	Example photonic product use cases
Advanced materials and manufacturing	High-energy lasers for material processing; optical sensors for process control; imaging systems for robotic assembly
AI, computing and communications	Sources/detectors/fibres/optical chips for quantum & 'classical' comm. systems; integrated optic quantum memory/processing
Biotechnology, gene technology and vaccines	Optical biosensors for pathogens; multiphoton fluorescent pathology/research tools; medical lasers; optical sensors for food quality
Energy and environment (incl. hydrogen)	Inherently safe H_2 sensors; methane leak detection; optical sensors for toxic materials; high-efficiency reflectors for lighting
Quantum	Entangled photon sources; integrated optic quantum state combiners/discriminators; 'macro-scale' photonic quantum simulation
Sensing, timing and navigation	Optical clocks, frequency combs; quantum optic magnetometers/ gravimeters; fibre laser hydrophones; Bragg grating sensor systems
Transportation, robotics and space	Bridge/roadway monitoring; free-space IR communications; robot's 'eyes'; lasers for planetary resource mapping; LIGO mirrors

Table 2.3
Applications and areas where photonics is used in Australia's *critical technologies*.

2.5 Global market for photonic products and components

As an economic engine for growth, the photonic marketplace is substantial and sustainable. Photonics is a core technology that provides critical enabling components, sub-systems, and systems to a broad range of industries. Understanding the photonic markets is a valuable resource for venture capitalists and policy makers seeking the best investment directions to ensure future economic strength and national security.

Data compiled by OIDA (OSA Industry Development Association), SPIE (International Society for Photonics) EPIC (European Photonics Industry Consortium), as well as several other organisations providing photonic market projections, including *Statista, Markets & Markets* and *Information Gatekeepers*, were reviewed and compared to the *Light Wave Venture* database to generate the market forecasts presented in this report and factor in current financial conditions.

In the 2016 report, the *'Lighting the Way'* team projected that the global market for photonics products would reach slightly over USD$600 billion (AUD$894 billion) in 2020. This has turned out to be a very accurate prediction, though actually exceeded by a small amount. The team's latest worldwide photonics product market projections are shown in Fig. 2.2.

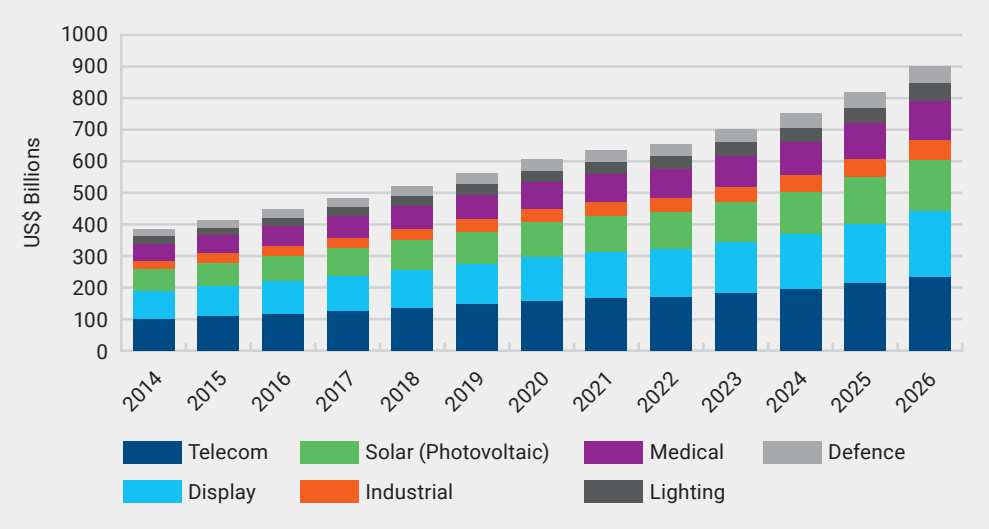


Figure 2.2
Worldwide photonics market by application

Despite the global problems associated with the Covid-19 epidemic, the 2020 forecasted sales met the earlier prediction. Based on the consensus of several independent market projections, by 2026 the market is forecast at USD$900 billion (AUD$1.34 trillion). Currently, the market growth has been hampered by material and component shortages, but by 2023, the compound annual growth rate (CAGR) is projected to be in the 7 to 9 per cent range. It is estimated that in 2022, the worldwide photonics industry already employs more than 4.1 million people. The various market segment forecasts are compared in 2020 and 2026 in Fig 2.3." to "in 2020 and 2026 are compared in Fig. 2.3.

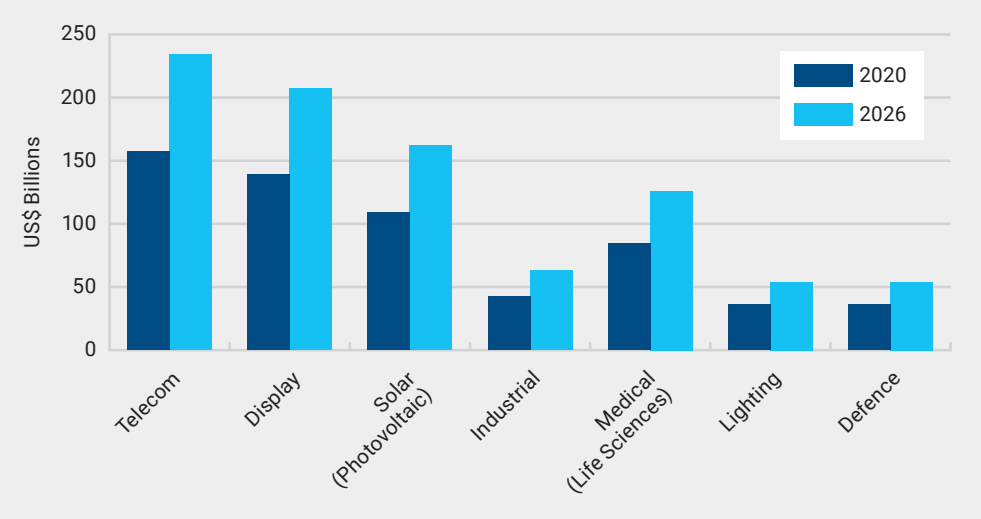


Figure 2.3
Comparison of market segments in 2020 to 2026

All photonic market segments are forecast to show strong growth over the next five years, with the potential for new market segments to emerge in space, transportation, and quantum computing.

The worldwide photonics market by region is shown for 2021 in Fig. 2.4. The dominant region is Asia Pacific. The Asia Pacific markets have advantages of lower manufacturing costs, but shipping costs and delays in getting products is a driving force for the market distribution to become more localised. As supply chains have been problematic in the current world situation, it is likely that North America and Europe will increase market share.

The fragility of the global supply chain will be an issue for Australia. Developing internal, cost- effective manufacturing capability is important to sustain growth and avoid manufacturing disruptions.

This forecast represents a worldwide projection for all photonics technologies. For South Australia, not all market segments are viable targets. For instance, the telecommunications market segment is dominated by Asian companies, and in many cases, products are considered commodity products which have high pressure on low selling costs and low-cost manufacturing. Other market segments could be problematic for South Australia. Solar energy is a potentially large market, but the competitive environment and shipping issues likely limit any Australian company to local sales. The defence industry faces barriers in penetrating the US markets. Experience with Canadian defence suppliers has shown great difficulty in dealing with 'not being made in the United States'.

There are key markets that can be addressed by South Australian companies that have a technology platform to support commercialisation.

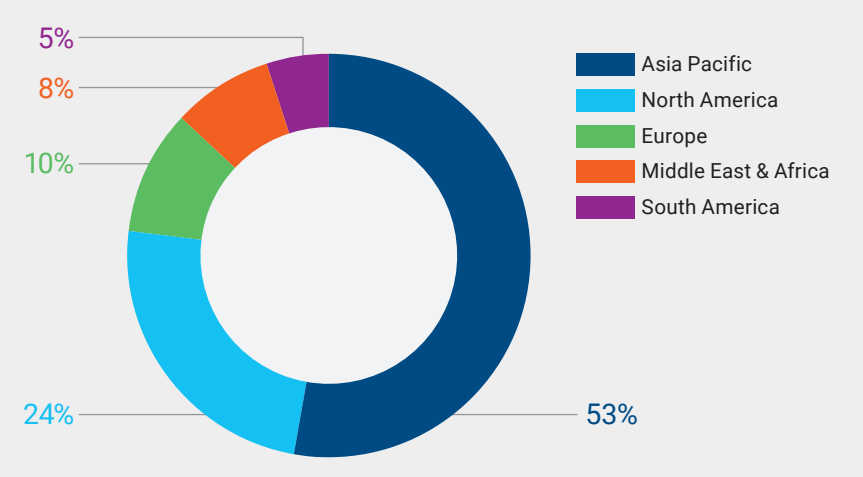


Figure 2.4
Worldwide photonics market by region 2021

2.5.1 Biophotonics market

Biophotonics uses light to diagnose and treat diseases in humans, animals and plants. It can also monitor biological systems associated with drug discovery and pharmaceutical production. In addition, biophotonics can be used to monitor the environment and chemical manufacturing. Another important application is associated with agriculture and food processing to maximise both production and safety. In the 2016 report, the biophotonics market was forecast to reach about USD$85 billion (AUD$127 billion) in 2020. The market forecast shown in Fig. 2.5 indicates the biophotonics market reached USD$84.7 billion (AUD$125 billion) in 2020 and is projected to grow to USD$126 billion (AUD$188 billion) in 2026.

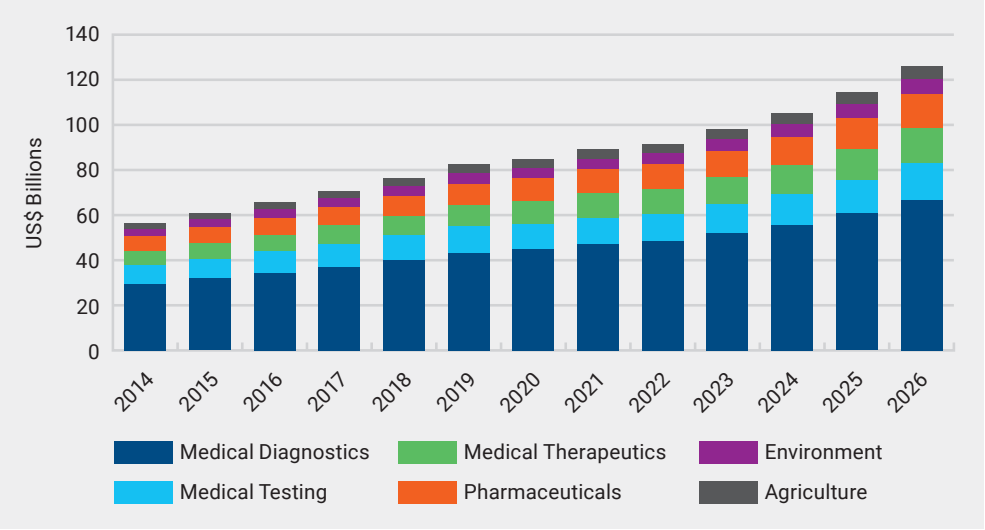


Figure 2.5
Worldwide biophotonics market by application

In 2026, the medical diagnostic and therapeutic applications represent about 78 per cent of the biophotonics market. Pharmaceutical applications represent about 12 per cent of the market. Environmental applications are at 5.5 per cent and agriculture and food processing represent just under 5 per cent of the market, but have a market value of USD$5.7 billion (AUD$8.5 billion). Biophotonics applications are compared in 2020 and 2026 in Fig. 2.6.

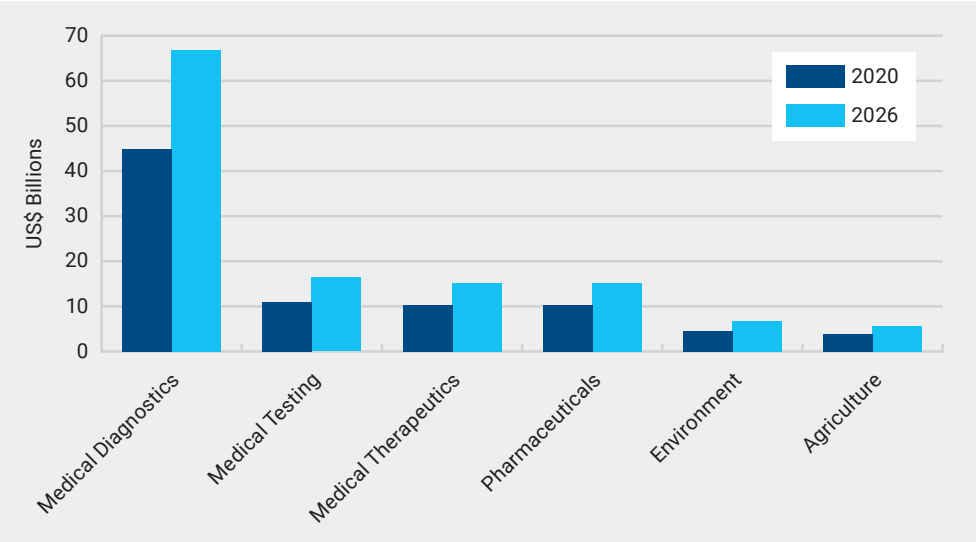


Figure 2.6
Biophotonics market segments comparison in 2020 to 2026

The market is showing substantial growth in all segments. The medical diagnostic segment is the largest in the biophotonics market. It includes optical in-vitro diagnostics, endoscopy, microscopy, spectroscopy, and imaging diagnostic tools.

The market for medical imaging is expected to grow from USD$15 billion (AUD$22 billion) in 2020 to USD$24 billion (AUD$36 billion) in 2026. Medical imaging applications include technologies such as scanning laser imaging, hyperspectral imaging, and optical coherence tomography. In addition, medical applications can expand to other life sciences applications, such as agriculture and food production, to help deal with issues associated with global warming. The worldwide biophotonics market by region is shown for 2021 in Fig. 2.7. North America is the dominant player associated with medical applications.

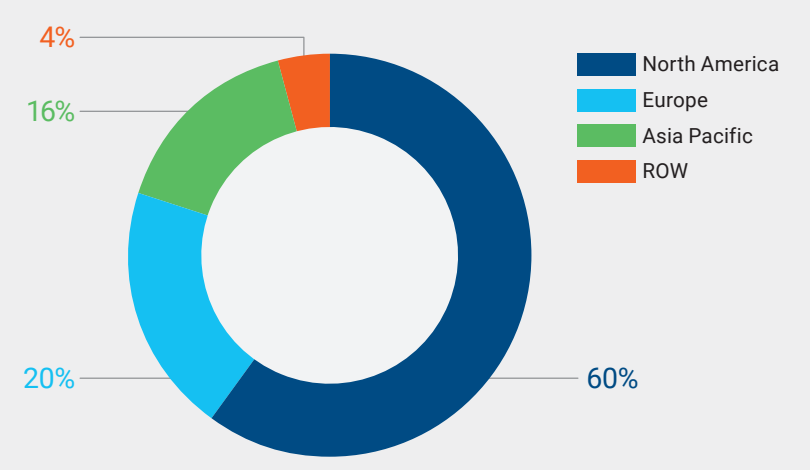


Figure 2.7
Worldwide biophotonics market 2021

2.5.2 Laser market

The laser market addresses many broad-based applications. The latest worldwide laser market projections are shown in Fig. 2.8. The total market for lasers is projected to approach USD$24 billion (AUD$36 billion) in 2026 with a CAGR of about 7 per cent. The three largest market segments are telecommunications, defence, and material processing, with a combined market share of 69 per cent. The sensor segment is 15 per cent, with the medical segment at 8 per cent.

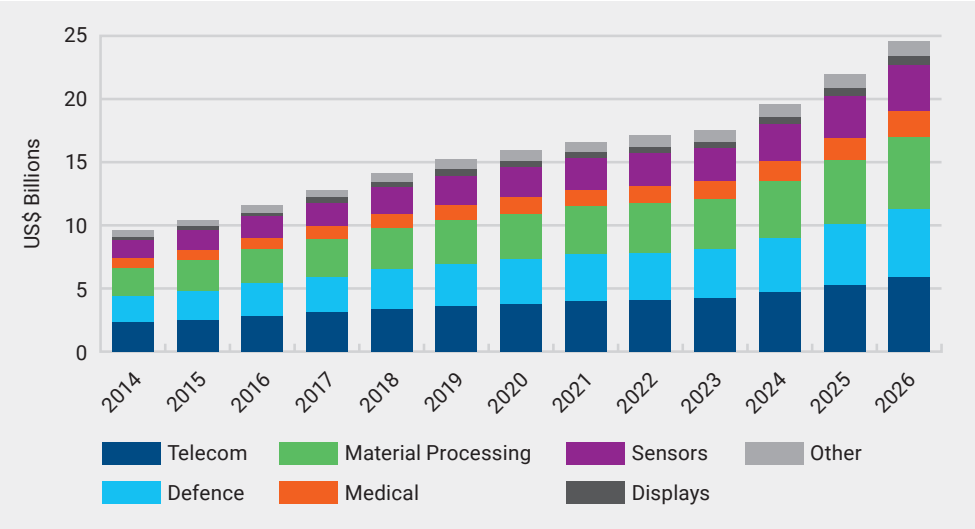


Figure 2.8
Worldwide laser market by application

The fibre laser market, shown in Fig. 2.9, will reach USD$4.7 billion (AUD$7 billion) in 2026, with a CAGR of about 12 per cent. Fig. 2.10 compares the total laser market to the fibre laser market in 2020 and 2026, showing the laser market share is projected to increase from 13 per cent to 19 per cent by 2026. The dominant market segment for fibre lasers is material processing.

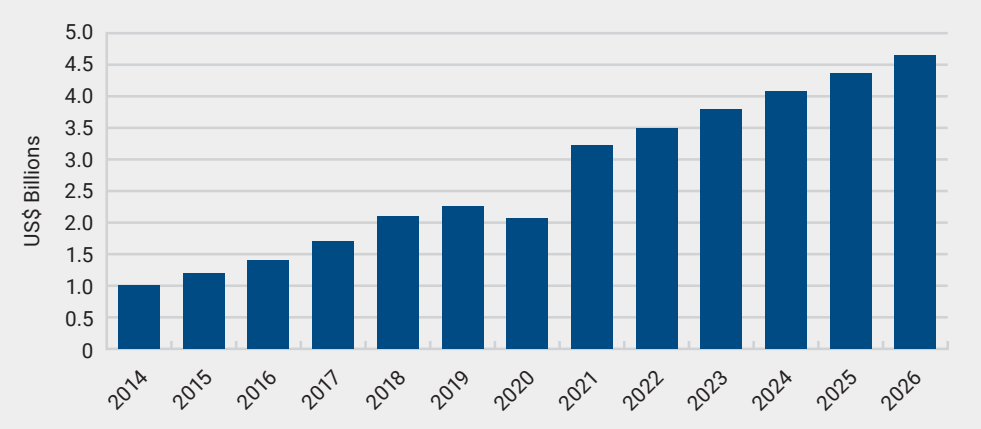


Figure 2.9
Worldwide fibre laser market

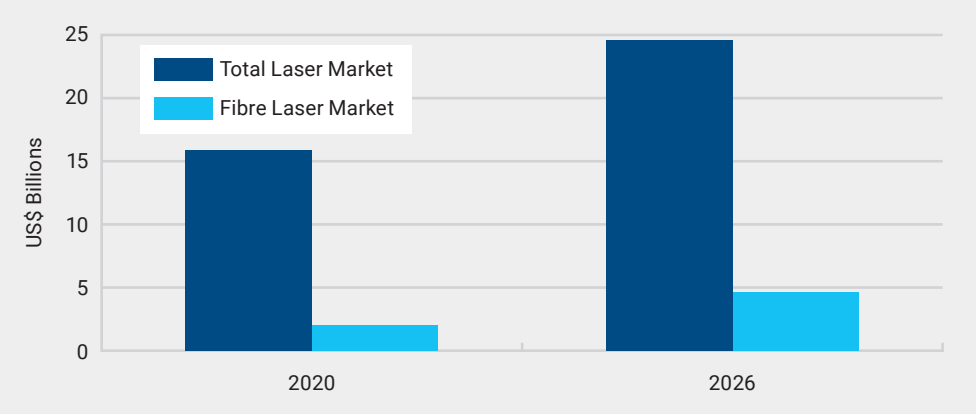


Figure 2.10
Total laser market to fibre laser market (2020 vs. 2026)

There is a growing market opportunity for lasers that function in the mid IR region (Fig. 2.11). Typically, these lasers will require rare earth doped fluoride or other glasses that can transmit in the mid IR wavelength range. Military applications have a 59 per cent market share.

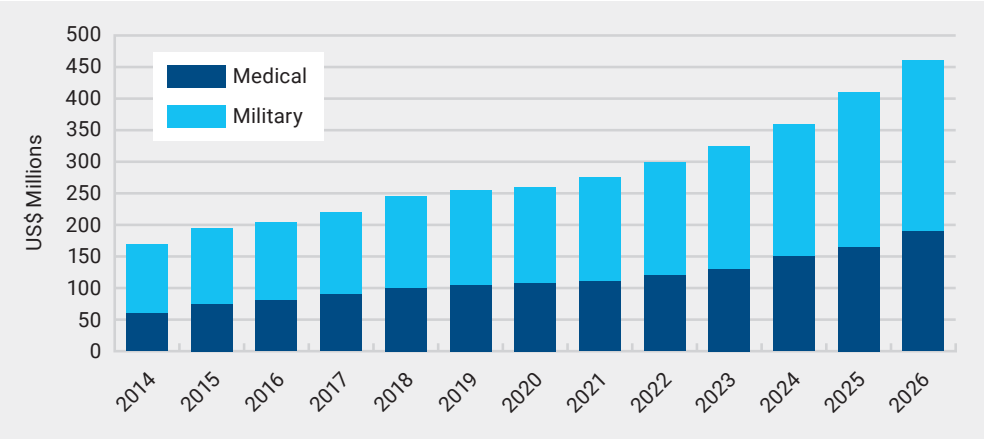


Figure 2.11
Mid-IR laser market

The worldwide laser market by region is shown for 2021 in Fig. 2.12. Asia Pacific and America are the dominant players as a result of sales associated with telecommunications, materials processing, and display applications.

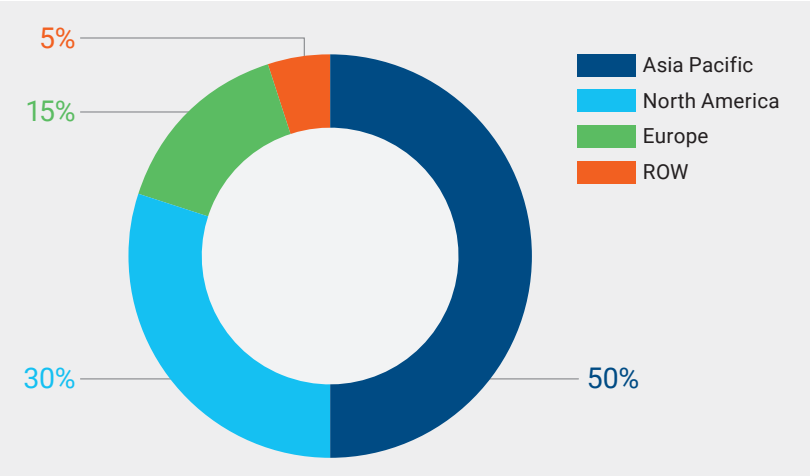


Figure 2.12
Worldwide laser market by region

2.5.3 Fibre optic sensor market

The sensor market is dynamically changing. Whereas this segment of the photonics market was previously dominated by sales to the energy industry, primarily to oil and gas exploration and production, there is now increased activity in the non-traditional energy sectors. The wind energy sector has some barriers, as the cost and size of wind turbines has significantly increased, but it will continue to grow, with the need for sensors increasing due to the size of the blades. Also, though the traditional energy business has been hit hard, the current price of oil is having a positive impact on the market. There is expected to be a small resurgence of the oil and gas market as carbon capture and storage (CCS) technology improves. Monitoring CCS reservoirs will provide an ideal application for intrinsic fibre optic chemical sensors – a speciality of IPAS. The current world situation will impact the defence and homeland security markets with an increase in spending. The smart infrastructure market will show significant growth. Supply-chain issues are affecting cost. Worldwide, there have been key acquisitions that are impacting relative market share, and the number of players has increased, including Chinese companies. The increase in companies has created an opportunity for strategic partnerships.

2.5.3.1 Distributed fibre optic sensor market

The market for distributed fibre optic sensors (DFOS) is shown in Fig. 2.13, while Fig. 2.14 depicts the distributed fibre optic sensor market by technology. Raman scattering sensors lost relative market share from 36 per cent in 2014 to 27 per cent in 2026 due the impact of the slower growth of the oil and gas market and increased need for static and dynamic strain sensing in other market segments. By 2026, Bragg grating technology sensors will have captured a 22 per cent market share. Interferometric sensing applications have about 16 per cent market share. But distributed acoustic sensing (DAS), which is rapidly gaining market share, is projected to be at 29 per cent by 2026. Brillouin scattering sensors are projected to have about 1 per cent market share. Attempts to commercialise distributed chemical sensors early in the 21st century were premature, but emerging market opportunities in the oil and gas industry have stimulated renewed interest in these kinds of products.

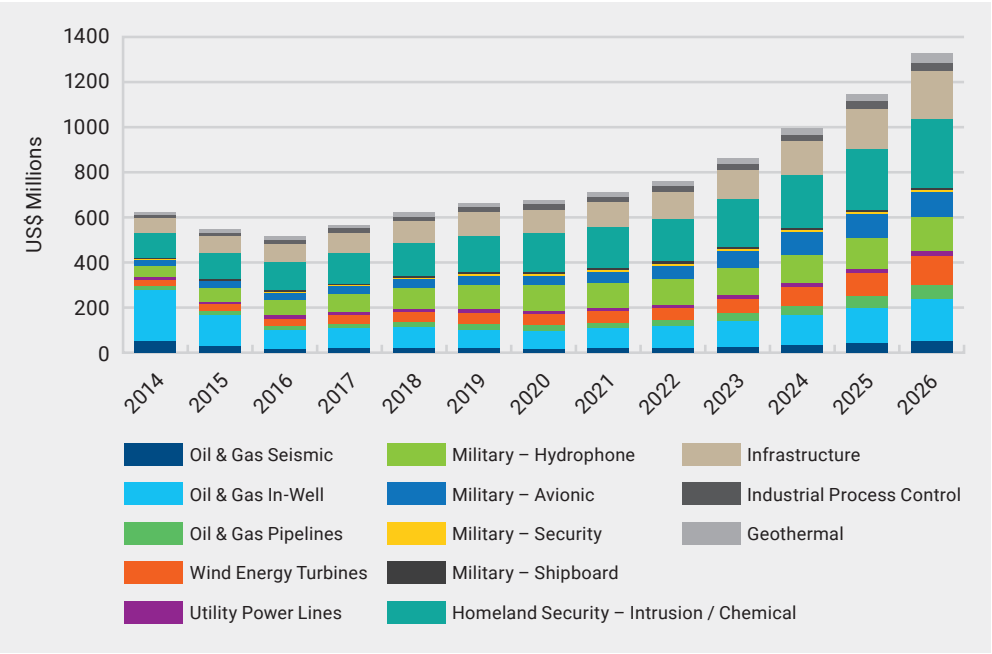


Figure 2.13
Distributed fibre optic sensor market (excluding China)

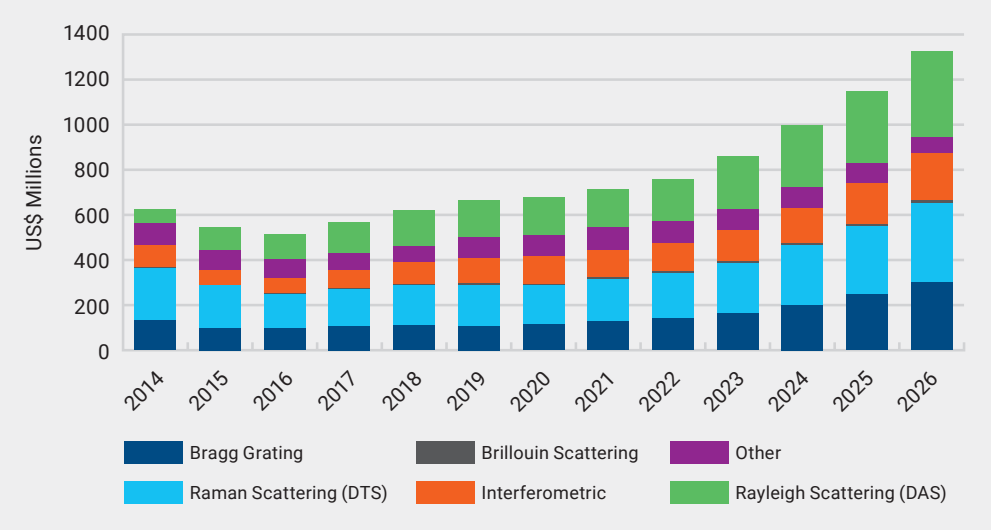


Figure 2.14
Distributed fibre optic sensor market by technology

The 2021 market shares for distributed fibre optic sensors (based on multiple Bragg gratings and on DAS) are illustrated in Figs. 2.15 and 2.16, respectively.

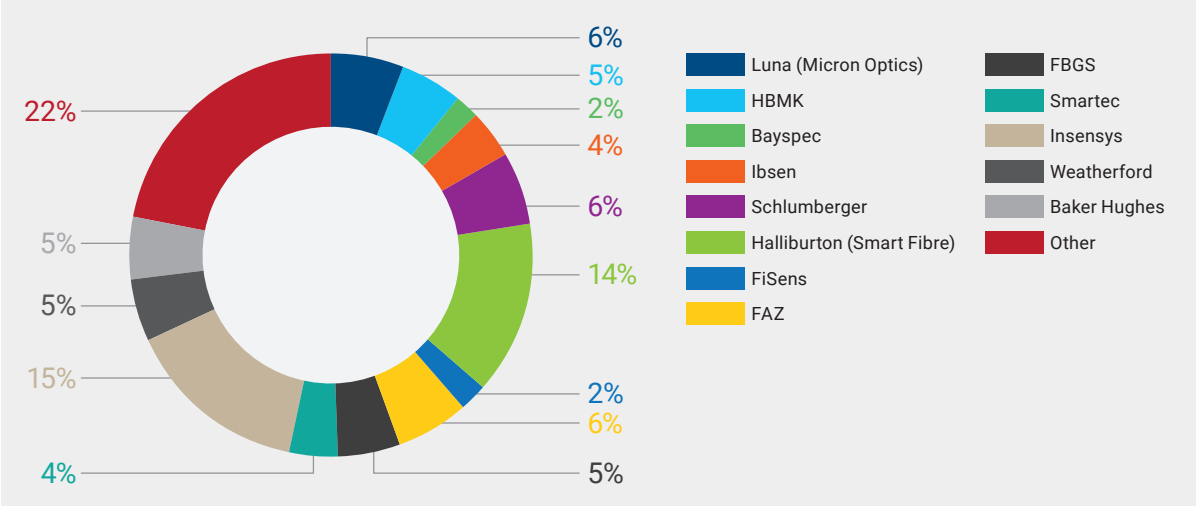


Figure 2.15
Distributed Bragg grating sensor market share 2021

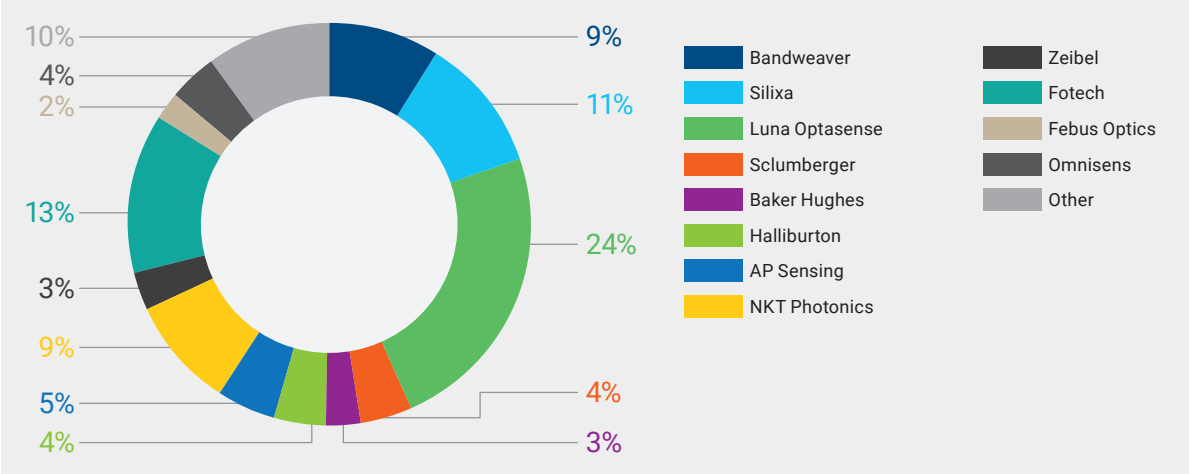


Figure 2.16
DAS sensor market share 2021

2.5.3.2 Fibre optic point sensor market

The fibre optic point sensor market is shown in Fig. 2.17. The market is dominated by gyroscope applications.

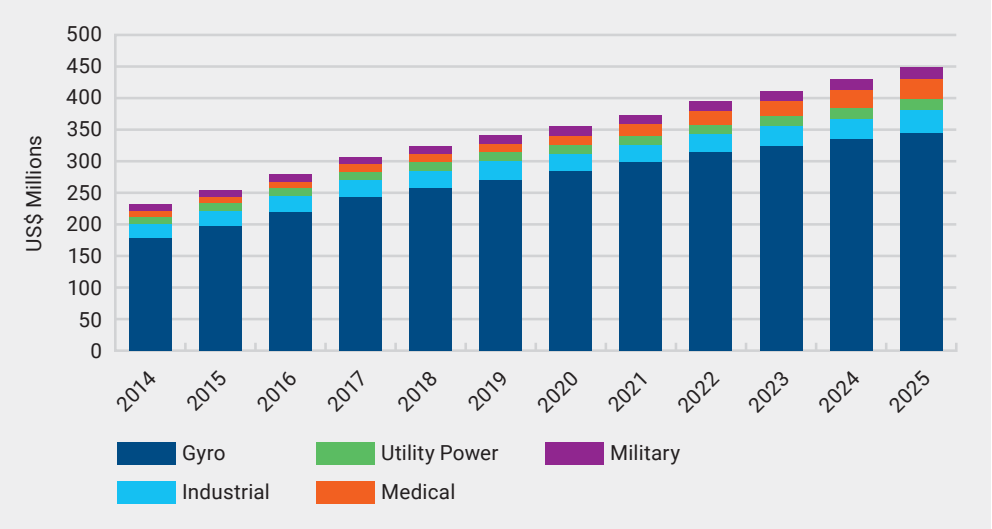


Figure 2.17
Fibre optic point sensor market by application

2.5.3.3 Other photonic sensor markets

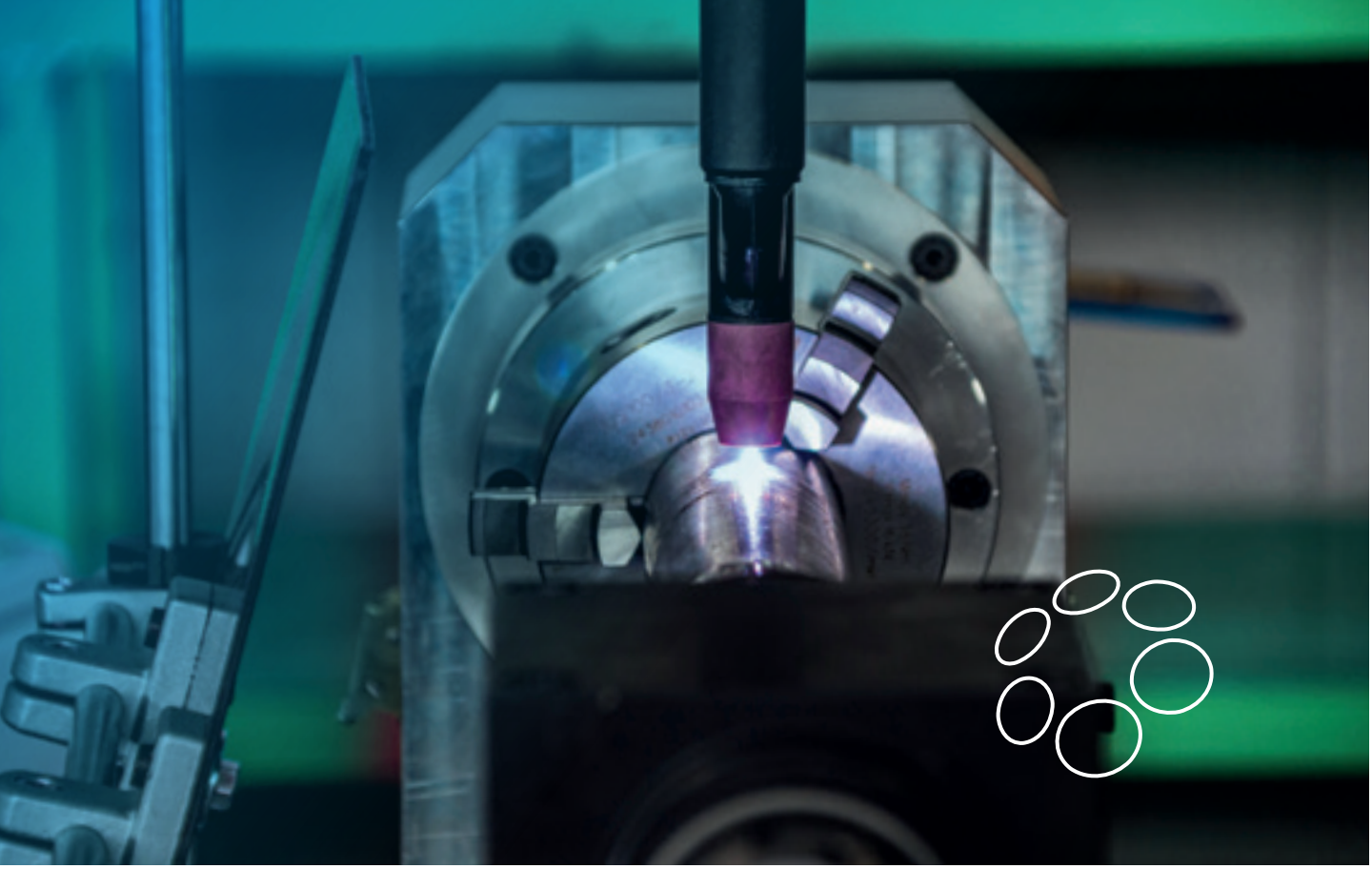
While fibre optic sensors are potentially the most important for South Australia, there are several other classes of light-based sensors and sensor systems.

1. ***Laser-based remote sensors***

   These sensors, which include LIDAR (distance-resolved air column characterisation), LADAR (laser ranging and profiling – often called LIDAR as well), and direct line-of-sight spectroscopy, are in use throughout the world. The LIDAR/LADAR market was valued at USD$1.3 billion (AUD$1.9 billion) in 2021 and is expected to reach USD$3.4 billion (AUD$5 billion) by 2026, at a CAGR of 22 per cent.

2. ***Micro-optic and integrated optic sensors***

   At the other end of the length scale, these extremely miniaturised sensors are primarily employed for chemical detection. They incorporate both active optoelectronic devices (sources, detectors, modulators, etc.) and sensor 'heads' into a single package. Chemical sensor examples include millimetre sized (bio)chemically active optrodes combined with like-sized optical components in injection-moulded housings and photonic integrated circuit (PIC) chips in which photonic waveguides carry light to chemically functionalised micro-ring resonators or to on-chip spectrometers. PIC chip structures that support entanglement and other exotic quantum states to perform ultra-precise physical measurements are also beginning to appear in the scientific literature. The development of integrated optic frequency comb generators – originally stimulated by the telecommunications industry – is also leading to the creation of new types of physical and chemical sensors. Fully integrated PIC sensors have yet to make significant product sales, but inherent ruggedness, small size, lightweight, and low power consumption of PIC chips make them so desirable for use in satellites, launch vehicles, and military systems that these markets present ripe opportunities. Furthermore, since large-scale PIC chip fabrication can achieve the extremely low costs associated with semiconductor manufacturing techniques, they have the potential to become consumer devices (e.g. adding food-quality or disease-detection features to mobile phones). Such a capability could lead to explosive market growth.



2.5.4 Specialty fibre market

The market for specialty fibre by product type is illustrated in Fig. 2.18. As the market grows, different needs will increase for radiation hardness, IR transmission, and higher temperature coatings. The specialty fibre for the sensor market is forecasted at USD$102 million (AUD$152 million) in 2026. The specialty fibre market is much larger if telecommunication and advance laser markets are considered. The needs will increase for fibre with increased bandwidth and IR function ability. It is projected that total specialty fibre will exceed USD$2 billion (AUD$3 billion) in 2026.

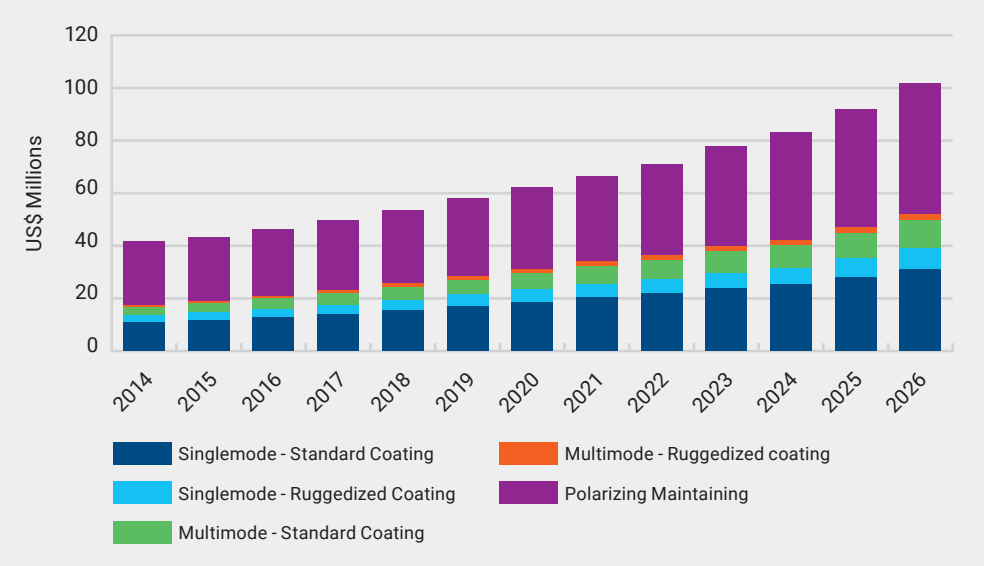


Figure 2.18
Specialty optical sensing fibre by product type

2.5.5 Quantum photonics market

The quantum photonics market segmentation by technology is shown in Fig. 2.19. The market is projected to grow from USD$650 million (AUD$967 million) in 2020, to USD$1.5 billion (AUD$2.2 billion) by 2026. There are a number of materials platforms for quantum applications. However, silicon photonics is the dominant technology, followed by silica glass.

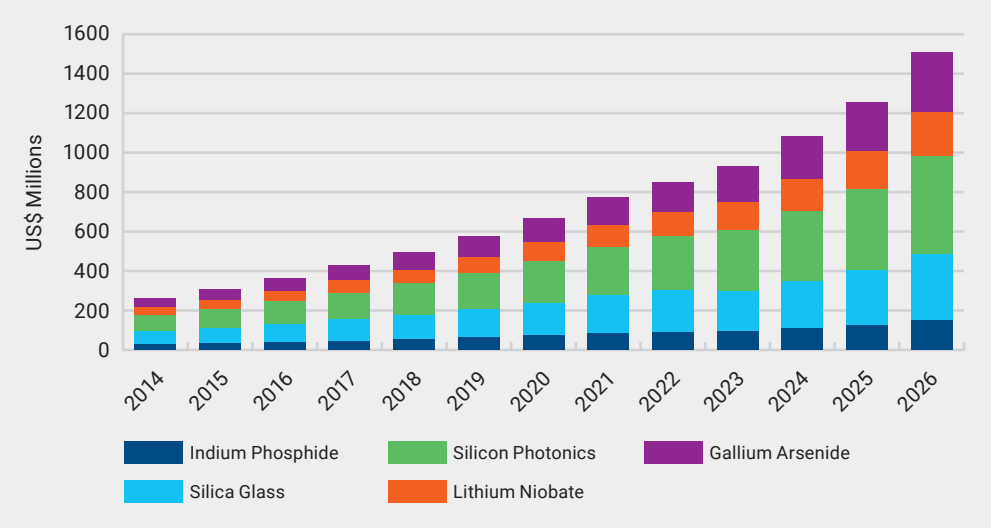


Figure 2.19
Quantum photonics market by technology

Figure 2.20 shows the quantum photonics market by application. In 2020 computing had the largest market share at 40 per cent, telecommunications had a 35 per cent market share, with sensing and medical at 15 per cent and 10 per cent respectively. The quantum photonics market by region in 2020 is shown in Fig. 2.21. North America has the largest share at 40 per cent, with Asia Pacific at 35 per cent and Europe at 20 per cent.

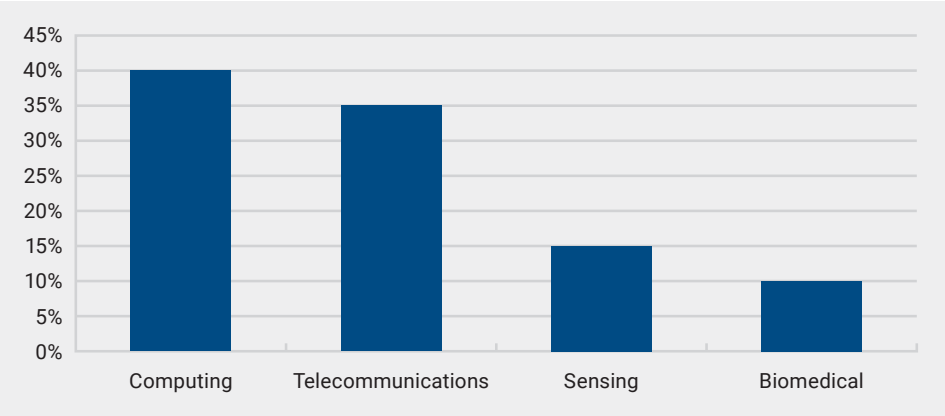


Figure 2.20
Quantum photonics market by application

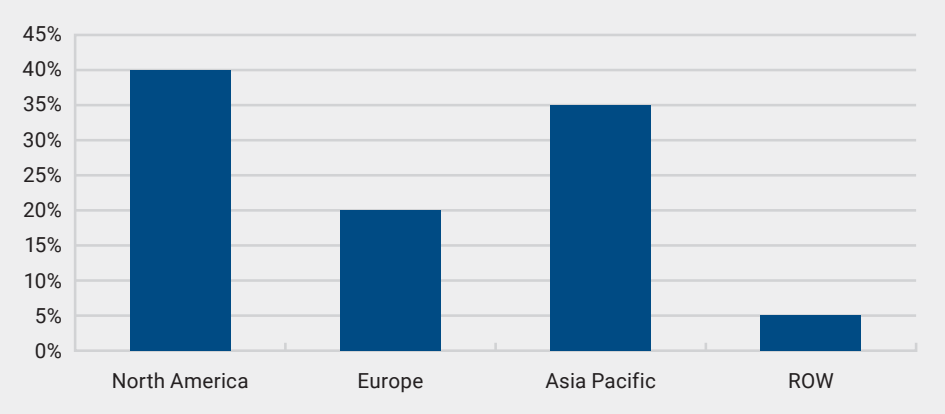


Figure 2.21
Quantum photonics market by region 2020

2.5.6 Photonics space market

Space applications by their nature are expensive, but they are providing solutions for driving needs such as communications, weather tracking, and space exploration. Photonics provides technology products to facilitate communications, navigation, scientific imaging, and sensing technologies. Much of the development is moving to the private sector to work synergistically with government agencies. The rapidly growing market shown in Fig. 2.22 was about USD$3 billion (AUD$4.5 billion) in 2016 and is projected to be about USD$26 billion (AUD$38.8 billion) in 2026. There will be a need for advanced imaging systems, enhanced navigation technology, improved radiation hardened fibre, and advanced laser technology.

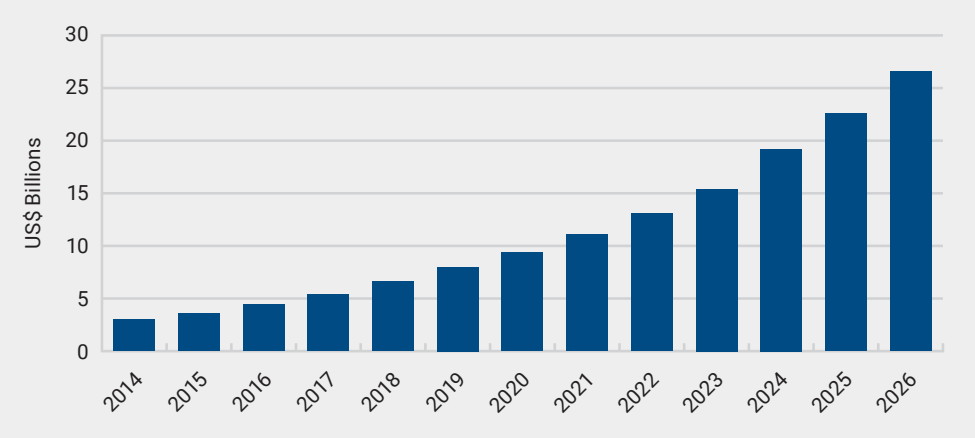


Figure 2.22
Space market for photonic components and systems

2.6 Economic and social impact of photonics

Australia has a strong and well-established academic base, and a long and reputable tradition of academic R&D, due to a wealth of expertise in areas such as precision optics, holography, optical fibres and components and, more recently, biophotonics. For a country of its size, Australia enjoys a very broad and diversified pool of researchers based on photonics R&D.

Photonics research in Australia started at the University of New South Wales (UNSW) back in 1966 with the arrival of Professor Toni Karbowiak from STL (Standard Telecommunication Labs) in the UK. Fortuitously, while at STL, Professor Karbowiak was the supervisor of Charles Kao, who won the 2009 Nobel Prize for his invention of glass optical fibres that could be used as a medium for telecommunication. Hence, there is a direct link from the birth of the optical fibre industry to the birth of photonics R&D in Australia, which continues to this day.

From industrial and commercial perspectives, the Australia photonics sector accounts for a total economic output estimated at AUD$4.3 billion, with 465 companies employing nearly 10,000 people[5]. It has a gross value added (GVA) per employee of approximately AUD$125,000, in line with the average for Australian manufacturing companies and similar in size to the mining and construction equipment, and the surgical and medical equipment manufacturing sectors in Australia.

The photonics industry is mostly concentrated in the urban population centres, particularly the eastern states of the country, as shown in Fig. 2.23. Firms of 50 employees or less account for 70 per cent of the companies and personnel employment in the sector.

The photonics output in South Australia is estimated to be USD$412 million (AUD$614 million), which is a two-fold increase from our prior reported estimate back in 2016 of AUD$200 million – certainly showing that the sector is healthy and thriving in South Australia.

Figure 2.23
Breakdown of the estimated photonics markets across Australia

Source: *Lighting Economic Growth: Photonics in Australia and New Zealand, an industry review*, by John Harvey, Simon Poole and John Lincoln. ANZCOP (2020).

5 Lighting Economic Growth: Photonics in Australia and New Zealand, an industry review, by John Harvey, Simon Poole and John Lincoln. ANZCOP (2020).

2.7 Local photonics market

The overall worldwide photonics market is forecast to reach USD$900 billion (AUD$1.34 trillion) in 2026. There are numerous opportunities in the areas of *biophotonics, lasers, sensors, specialty fibres* with new markets emerging in *quantum photonics*. South Australia itself provides significant local opportunities in key subsets of this enormous market. Success in the state can easily lead to success for the whole of Australia, and provide a springboard to major offshore markets.

The South Australian Government has identified areas for local growth. **Agribusiness** can be strongly supported by biophotonic sensors, and by advanced imaging systems, in facilitating crop growth optimisation, advanced food processing and veterinary medicine. **Business services** are improved with high-speed fibre optic data transmission and signal processing systems based on photonic integrated circuits. **Creative industries** can emerge from advanced optical sensing and lighting technologies, and innovative 'colour-tunable' glasses that provide new artistic opportunities. **Defence** can benefit from photonic security and surveillance systems, airborne/shipboard structural health monitors, quantum navigation, and missile defence systems. The **digital** world can greatly benefit from advanced optical platforms that generate entangled photons and other exotic states for quantum computing and communications. The **energy** sector uses optical sensor technology for many applications, including hydrocarbon exploration and production, in hydrogen, CO_2, and methane leak detection, and for monitoring the structural health of carbon-free power sources (e.g. wind/tidal generators). Photovoltaics plays a key role in solar energy applications. **Health** is an area in which biophotonics has and will continue to play a critical role in both therapeutics and diagnostics – from cancer detection to laser surgery and beyond. While photonics is itself a hi-tech industry, other industries in this sector often rely on photonic technology, including advanced products for **space** applications. Free-space optical communication systems, satellite/launch vehicle monitoring, space-borne infrared and other imaging systems for weather monitoring and exploration are but a few examples.

There are opportunities for South Australian companies to be key players in the photonics market in areas such biophotonics, laser, sensors, specialty optical fibres, advanced materials, and quantum photonics.

2.8 Overview of South Australian photonics technology strengths

The strong photonics technology base established in South Australia over several decades has continued to grow in the period since *Lighting the Way* was released, despite obstacles posed by the global pandemic in the last few years. New funding has led to robust support at the University of Adelaide for existing programs, and to a significant expansion of capabilities brought by newly-hired researchers. Photonics research has remained stable at UniSA, and improved coordination between these two institutions and DSTG has accelerated progress in key research areas, both for the exploration of new ideas and for the development and transfer of commercially viable technologies. Flinders University has become a 'victim of its own success' since its main photonics research activity – fibre optic sensor R&D – has successfully moved off-campus into a commercial enterprise. However, the DSTG research facility in Edinburgh has maintained its position as an important source of photonics-related applied research.

There has been little, if any, attrition among existing players in the corporate side of the 'photonic ecosystem', and new companies are beginning to emerge (see Fig. 2.24). As a result, total corporate spending on research and development activity has also grown. Overall support in the past several years has allowed South Australia to maintain and even expand its leadership position in the development and application of photonic systems based on unique laser capabilities. This reinforces the 2016 roadmap's projection of the benefits of continuing to invest in photonics.

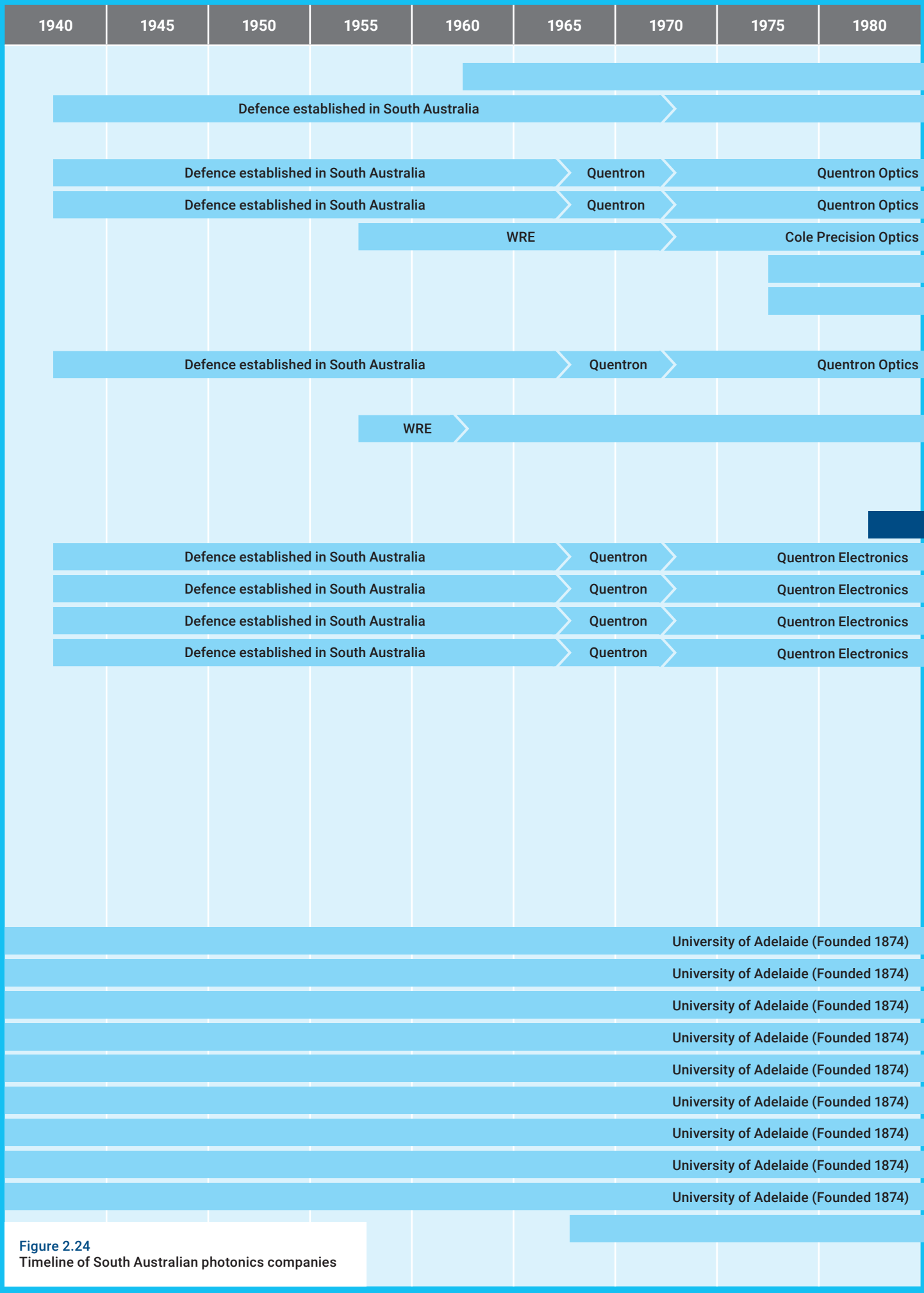
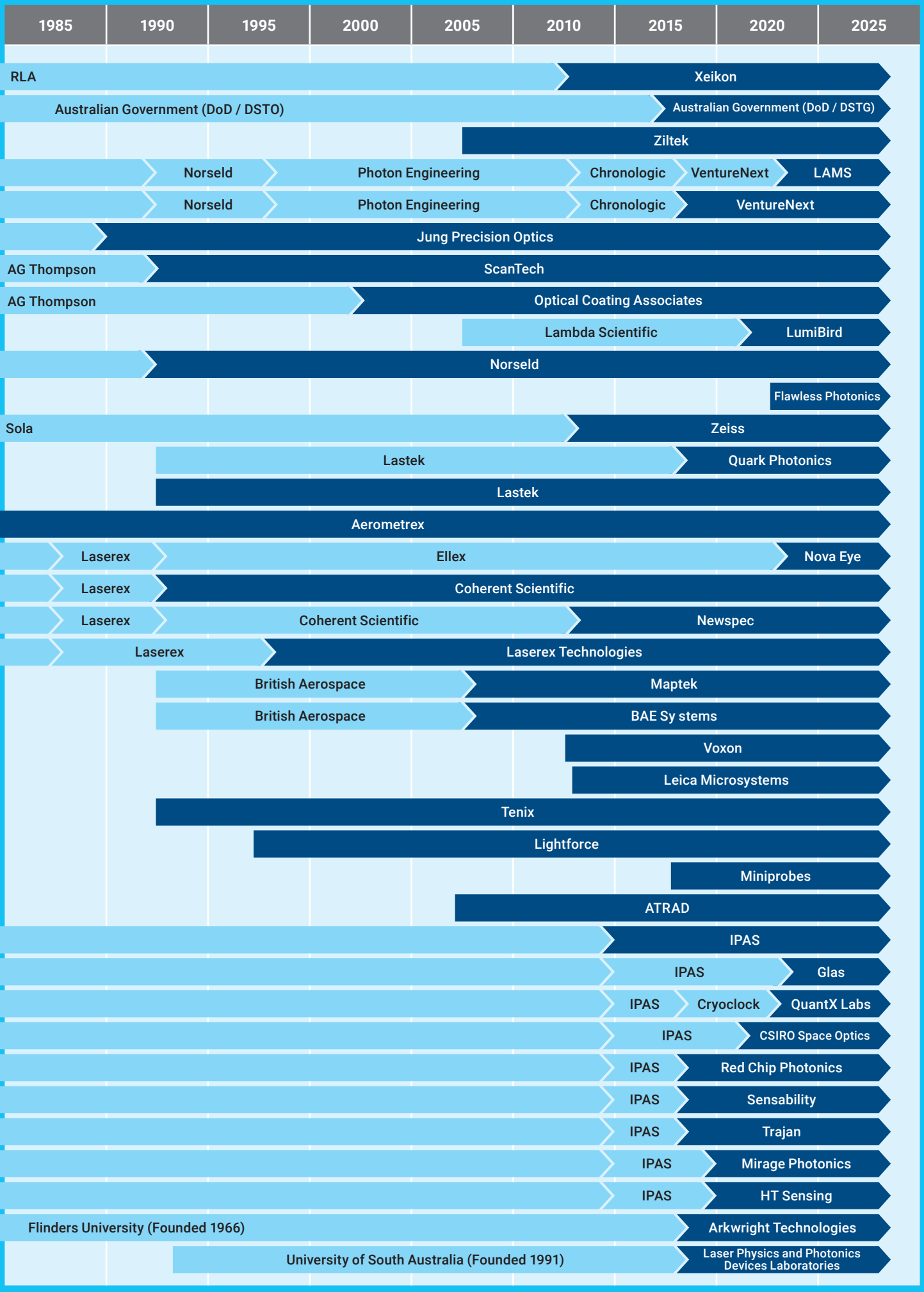


Figure 2.24
Timeline of South Australian photonics companies


1985
1990
1995
2000
2005
2010
2015
2020
2025
RLA
Xeikon
Australian Government (DoD / DSTO)
Australian Government (DoD / DSTG)
Ziltek
Norseld
Photon Engineering
Chronologic
VentureNext
LAMS
Norseld
Photon Engineering
Chronologic
VentureNext
Jung Precision Optics
AG Thompson
ScanTech
AG Thompson
Optical Coating Associates
Lambda Scientific
LumiBird
Norseld
Flawless Photonics
Sola
Zeiss
Lastek
Quark Photonics
Lastek
Aerometrex
Laserex
Ellex
Nova Eye
Laserex
Coherent Scientific
Laserex
Coherent Scientific
Newspec
Laserex
Laserex Technologies
British Aerospace
Maptek
British Aerospace
BAE Sy stems
Voxon
Leica Microsystems
Tenix
Lightforce
Miniprobes
ATRAD
IPAS
IPAS
Glas
IPAS
Cryoclock
QuantX Labs
IPAS
CSIRO Space Optics
IPAS
Red Chip Photonics
IPAS
Sensability
IPAS
Trajan
IPAS
Mirage Photonics
IPAS
HT Sensing
Flinders University (Founded 1966)
Arkwright Technologies
University of South Australia (Founded 1991)
Laser Physics and Photonics Devices Laboratories

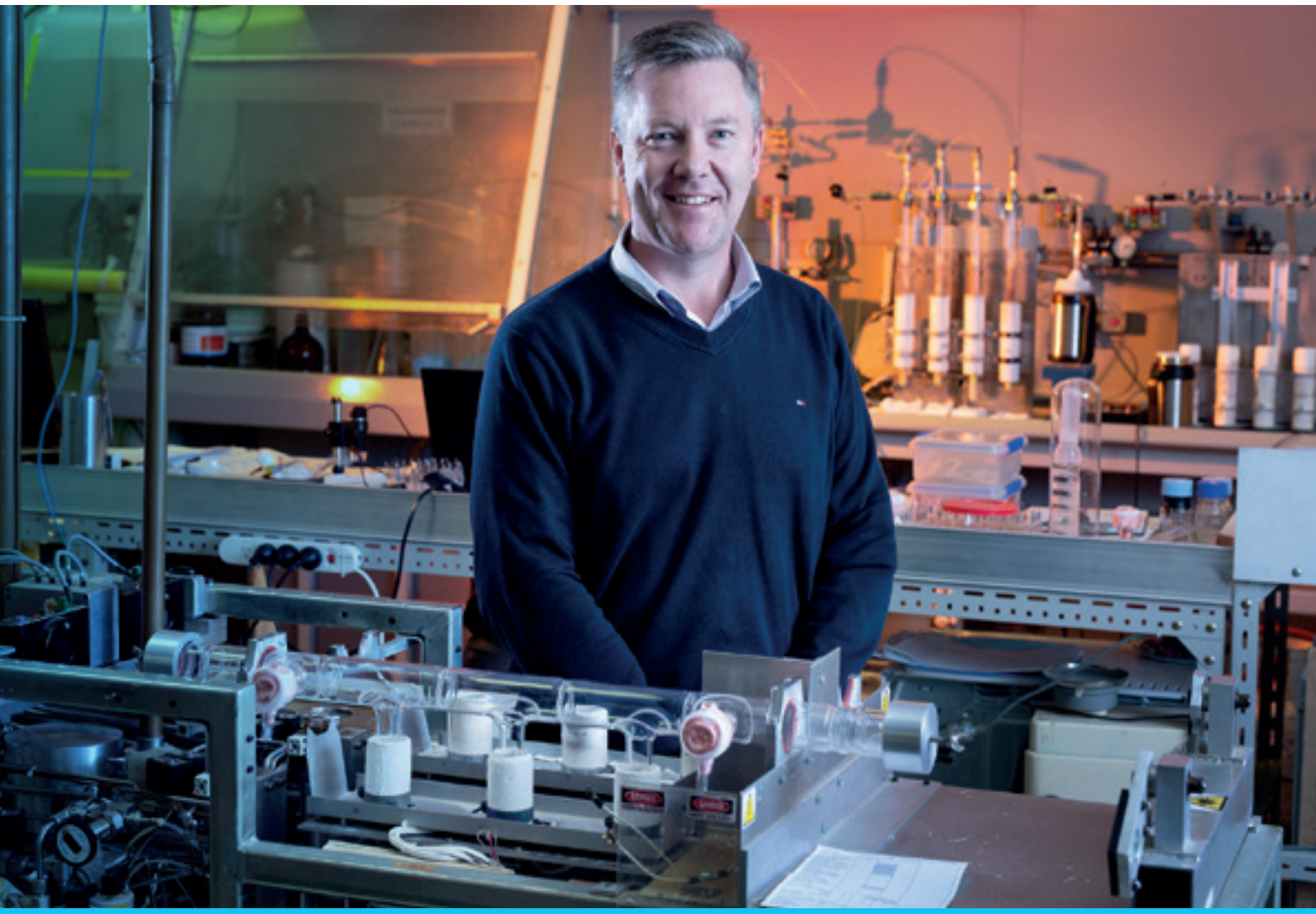
The major research competencies identified in *Lighting the Way* have grown even stronger since the roadmap was released, and new areas of strength are beginning to emerge. Solid state laser technology development based both on novel semiconductor structures and on unique glass compositions is poised to create a 'second wave' of unique light sources that will maintain and expand South Australia's longstanding leadership in Australian laser-based businesses.

A significant change has been the rapid strengthening of quantum optics and quantum-related photonics research and development in the past six years. With important defence and space applications, this rapidly growing field has already begun to bear fruit in the form of commercial activity, and holds great promise for significant scientific and commercial advances during the next decade. The addition of senior faculty members at the University of Adelaide promises to revitalise research in biophotonics, already a well-established competency in South Australia.

South Australia's unparalleled expertise in creating and fabricating exotic glass compositions and unique structures in bulk and fibre optical materials continues to be an important factor that underpins much of the state's strength in photonic research and development. Ongoing research into post-processing methods for creating refractive index patterns (e.g. fibre Bragg gratings and planar waveguides) in these materials is a key element in producing useful structures and devices – particularly advanced optical sensors – based on these materials.

Our updated market analysis and extensive interviews have shown that South Australia remains strong, and in fact has grown stronger, in photonic technologies that address the four key market sectors identified in *Lighting the Way*. In the past five years, highly encouraging new activity in quantum photonics adds this important and rapidly growing field to our list. There are many crossovers and synergies between these broad areas, and it is sometimes difficult to place individual opportunities neatly into one category, but taken together they provide a fruitful base for rapid growth. So now we state that there are five key photonics-related market sectors of significant relevance and benefit to South Australia, namely:

1. **Biophotonics** – imaging and diagnostics for biomedicine, agriculture, and environment
2. **Lasers** – for military, space, biomedical, industrial, and mining
3. **Optical sensors** – for environmental, space, security, energy, military, and safety
4. **Specialty glass and optical fibres** – enabling technology for all of the above.
5. **Quantum photonics** – ultrasensitive measurements for military, space, and geophysics



03. Summary and conclusions

Photonics research in South Australia, already quite healthy, has strengthened considerably since 2017. With the addition of impressive new research scientists at the University of Adelaide and the Defence Science and Technology Group, new facilities such as III-V semiconductor development capability, and a significant increase in funding, the state has unquestionably positioned itself to become a globally leading centre of excellence in five key areas of applied photonics. The results of investing in high-quality research talent over the past five years are abundantly clear: photonics research in Adelaide is stronger than ever. If this level of support is maintained, another five years will see Adelaide clearly recognised as being at the forefront of these core photonics disciplines:

- South Australia's ***specialty glass and fibre optics*** expertise is absolutely world-class, with many materials development and fabrication capabilities that cannot be found anywhere else. This important proficiency underlies much of the progress in other areas.
- ***Laser science***, a longstanding research strength in South Australia, is still strong. Established capabilities in planar and fibre optic configurations have evolved so that lasers in the laboratory are now operating at vastly increased power levels. Notable work is also being done on lasers that can generate multiple wavelengths over important ranges of the optical spectrum, enabled by unique designs and new laser glasses.
- ***Quantum photonics*** is now well-established in South Australia. The tight focus of this increased capability of sensing and metrology has already borne fruit in the form of a rapidly growing commercial spin-off company, far ahead of many quantum research groups in the rest of the country.
- Work on fibre-based ***optical sensing*** has resulted in the development of impressive military hydrophone array technology and two small start-up companies with large market potential. With this maturation, research on fibre sensors appears to have diminished, but work on optoelectronic sensors, particularly infrared detectors and imaging arrays, together with work on laser-based remote remains very strong at both types of facilities.
- Research in ***biophotonics*** has been revitalised within the past year by the addition of an ARC Laureate Fellow and several support research staff at the University of Adelaide. Cutting-edge research on cellular and sub-cellular manipulation, advanced microscopy, and light-tissue interaction could well result in a new generation of potential applications.

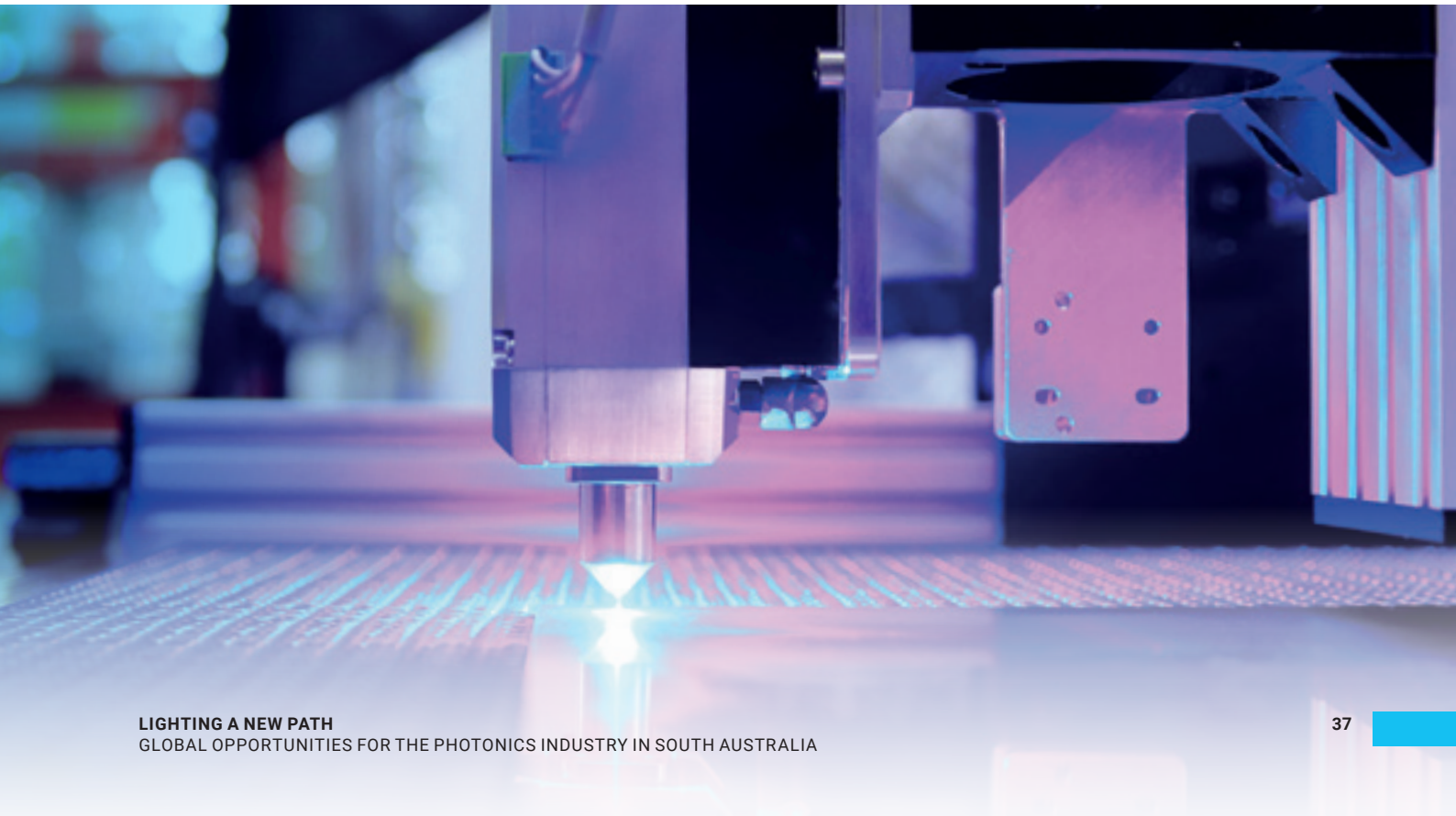
The **photonics business community** in South Australia has grown more slowly than expected over the past five years. The photonics research already done in Adelaide presents major business opportunities that can yield revenue soon:

- **Military products** – There are several near-term opportunities for South Australia to use its photonics expertise to establish manufacturing capabilities for important defence-related products. Adelaide's cadre of defence contractors can manufacture and support these critical products, providing the ADF with an Australian sovereign source of supply, resulting in significant employment and revenue.

- **Infrastructure monitoring** – Well-established local photonics expertise, already embedded in start-up companies, can be leveraged to address an array of problems faced by owners of large-scale civil assets. Ageing bridges and other railroad and highway structures are a prime market for Adelaide's fibre optic sensing expertise. South Australian sensors could address this need, starting in Australia (already a lucrative market) and ultimately the rest of the world.
- **Space communications and sensing** – The new South Australian space economy is creating a local market for advanced photonic products that can be used for free-space optical communications, earth observation, and other applications. This offers an excellent opportunity for the founding of new businesses, particularly if supported by a shared capability to engineer and fabricate space-qualified products.
- **Medical products** – Companies that make surgical laser systems are still the biggest single source of photonics revenue in South Australia. Local research in advanced laser systems can significantly reduce the cost and improve the performance of their products, opening up large new markets around the world and improving profit margins. These established businesses also may offer a platform for development and distribution of other medical products, particularly biosensors.
- **Mining and manufacturing** – Many photonics-enabled products are already being produced in South Australia for the mining industry. This sector, together with heavy industry, has the potential to provide rapid economic growth if corporate engineers collaborate with academic researchers to convert promising new technologies into rugged, reliable products.

This wealth of opportunities shows that, by not focusing on fibre optic telecommunications, South Australia has been able to establish, and take advantage of, attractive opportunities in many other less competitive, higher return branches of the photonics business.

Photonics is a foundational technology. Photonics and photonics-enabled products are ubiquitous in daily life, and are essential to the success of many other technologies and industries of the future, from quantum devices and systems to sensors for the Internet of Things. South Australia's unique areas of expertise in photonics have poised it to participate in numerous lucrative markets and to rise head and shoulders above other states in this dynamic and rapidly growing industry.



Appendix A – Biographical sketches of road-mapping team

Dr. Robert A. Lieberman

Dr. Robert A. Lieberman is a Member of the US National Academy of Engineering and President of Lumoptix LLC. He received his PhD in Physics with an emphasis on solid-state physics and biophysics from the University of Michigan in 1981. Dr. Lieberman then joined AT&T Bell Laboratories where he was a member of the technical staff in the Magnetics and GaAs Development departments, and the Biophysics and Glass (Fiber Optics) Research departments for 10 years. He moved to Physical Optics Corporation (POC) in 1991, where he became the Vice President and General Manager for Research and Development. In 1998 he left POC to found Intelligent Optical Systems Inc. (IOS), a 50-person company dedicated to applied research on optical and photonic technologies, with a business model focused on transferring developed technologies out of the company and into appropriate product-focused entities (spin-offs, start-ups, licensees) for commercialisation. Simultaneous with his business activities at POC and IOS, he maintained an active scientific career, serving as principal investigator on research and development projects for the US National Institutes of Health, NASA, the National Science Foundation, and the Departments of Energy, Defense, and Homeland Security. Dr. Lieberman retired as President and CTO of IOS in 2014 to focus on Lumoptix LLC, a company he founded in 2010. He holds 34 US patents, has chaired more than 50 international conferences and symposia on fibre optic physical sensors, biosensors, and chemical sensors, and has published extensively in the field of optical sensing.

Dr. Lieberman was elected to the National Academy of Engineering in 2016. He is a Fellow of SPIE, a Senior Member of IEEE, has served as an editor and reviewer for more than 20 journals, and is on the boards of directors of IOS, OpTech Ventures, Optinetrics, Sensorware Systems, OptiSense, Optical Security Sensing LLC, Intellisense Systems, SPIE, and the South Bay Science Center. He serves on the International Steering Committees of the Europt(r)ode Conference on Optical Chemical Sensors and Biosensors, the Advanced Course on Optical Sensors, and the European Workshop on Optical Fiber Sensors, and chaired ASTM Subcommittee E13.09 on Standards for Optical Waveguide Chemical Sensors. He is the 2008 winner of the SPIE President's Award, three NASA Space awards, and three Bell Labs Exceptional Contribution Awards.

In addition to his ongoing work in optical sensing and photonics business development, Dr. Lieberman's current interests include national and international science policy, science education issues, and translational research in optics and photonics. He has arranged testimony for the US Congress on the economic importance of optical sensors, and was a keynote speaker at several events during the United Nations International Year of Light in 2015. Dr. Lieberman was the 2016 President of SPIE, the International Society of Optics and Photonics, and is a longstanding member and sometime Chair of the organisation's public policy and corporate relations committees. He is also a founding member of the US National Photonics Initiative (http://www.lightourfuture.org), which was instrumental in the formation of the American Institute for the Manufacture of Photonics (AIM Photonics).

Dr. David Krohn

Dr. David Krohn has more than 50 years of experience in the photonics industry. He is the Managing Partner of Light Wave Venture LLC, which is focused on developing telecommunications, sensor, power delivery and energy related business opportunities. He has assisted more than 125 companies with activities in marketing, planning and management functions as well as technical input. In prior experience, he served as Global New Business Director for Photonics at 3M Company. From 1987 to 1998, he was the General Manager of the 3M Specialty Optical Fiber Business that included the Bragg Grating Technologies business acquired from UTC in 1995. He founded EOTec Corporation in 1979, which manufactured specialty fibre, sensors, cables, cable assemblies and data links. He was the CEO of EOTec until the business was acquired by 3M in 1987. At this time, he is also active in many technical societies, and teaches short courses in technology and business development at various universities. He started and is the current chair of the Photonic (Fiber Optic) Sensor Consortium, which has more than 60 participating companies and organisations. He is also the chair of the IEEE Fiber Optic Sensor Standards Activity. As the photonics marketplace has radically changed in the last several years, he has worked with several companies to diversify into non-telecommunication markets such as military, homeland security and biomedical. He has extensive experience in laser related technology including lighting and power delivery.

Dr. Krohn has significant experience in the technical aspects of photonic design and fabrication, and is currently active in the development of advanced photonic components and systems. He played a key role in the development of polarising maintaining (PM) fibre, which is a critical component in advanced fibre optic gyro systems. He is a co-author of the book *Fiber Optic Sensors: Fundamentals and Applications*, Fourth Edition (2014), and the author of the book *Commercialisation Basics for the Photonics Industry*, (2013).

Dr. Krohn attended Rutgers University as an undergraduate (BS 1965). He obtained his MS from Case Western Reserve University in 1967 and his PhD from Lehigh University in 1973. All his degrees are in materials science. He has written six books (four on fibre optic sensors) and more than 75 papers, and holds 27 patents relating to photonics. Recently, he started CITE (Commercialization of Innovative Technology through Entrepreneurship).

Dr. Alexis Méndez

Dr. Alexis Méndez received a PhD in Electrical Engineering from Brown University, USA in 1992. He is president of MCH Engineering LLC—a consulting firm specialising in optical fibre sensing and photonics technology. Dr. Méndez was the former Group Leader of the Fiber Optic Sensors Lab within ABB Corporate Research (USA) where he led R&D activities for the development of fibre sensors for use in industrial plant, oil and gas, and high voltage electric power applications. He was also the former engineering manager at Phaethon Communications, Director of Engineering at Arista Networks, and Director of Sensing Solutions at Micron Optics. He has written more than 70 technical publications, taught multiple short courses, holds five US patents, and is recipient of an R&D100 award.

Dr. Méndez is a member of the OFS International Steering Committee, a Fellow of SPIE and was past Chair of the 2006 International Optical Fiber Sensors Conference (OFS-18), and past Technical Chair of the 2nd Workshop on Specialty Optical Fibers and their Applications (WSOF-2). He is also committee member of ISHMII (International Society for Health Monitoring of Intelligent Infrastructure), as well as VP of the IEEE Fiber Optic Sensors Standards Committee. He is co-editor of the *Specialty Optical Fibers Handbook*, and co-author of SPIE's *Fiber Optical Sensors Book — Fundamentals & Applications, 4th Ed.*

Appendix B – Key considerations for international sales

Most photonic and photonics-based products offer truly international market opportunities. Australia provides an excellent environment for perfecting photonic products and sales strategies that can achieve success in the wider world, particularly the developed countries of north America and Europe. Although respectable sales revenues can be achieved in-country, if these funds are leveraged to launch products into international markets, an Australian photonics company can grow to many times its initial size. The best way to accomplish this transition is to identify discrete entry points within the worldwide economy, to work with companies that already have an international presence, to create international brand recognition for South Australian photonics excellence, and to take advantage of market-specific programs and organisations that can foster international trade and provide valuable connections in target markets. This section briefly covers some ways to accomplish these things.

B.1 Countries to be targeted for exports

The countries that offer the best return on investment in South Australian photonics sales will depend on the marked segments targeted by those products. The list below should contain few surprises, but does offer a framework for considering when and where to launch international sales efforts:

- Defence products (e.g., Cryoclock, fibre laser hydrophone):
  - NATO countries (particularly UK, USA, and Canada)
  - Japan
- Medical laser products (e.g., surgical lasers and biosensors):
  - Asia (specifically countries where Ellex and Norseld are selling)
  - USA
- Infrastructure monitoring sensors (e.g., FBG systems for rail, bridges, etc):
  - EU countries
  - Japan
  - India
  - USA
- Industrial process sensors (e.g., high-temperature sensors, vibration monitors):
  - Japan
  - India
  - USA
- Pipeline monitors (e.g., drone-based IR spectrometry):
  - USA
  - Canada

- Meat grading systems:
  - USA
  - Argentina
  - EU countries
- Mineral exploration and extraction (ore grading, remote prospecting):
  - Canada
  - USA
  - Chile

B.2 International forums for South Australian photonics

Photonics West

The world's largest scientific conference on photonics, and (in alternating years) the largest exhibition of photonics products, this event is held annually in San Francisco. South Australia should encourage its photonics researchers to present more research at this Symposium and should resume its presence in the exhibit hall.

Laser World of Photonics

When it is held (every other year), this event in Munich is the largest exhibition of photonics products in the world. A relatively small, affiliated conference is held in conjunction with the event. South Australia should send at least one person to this event, and consider exhibiting.

Defense and Commercial Sensing (DCS)

This event in Orlando, Florida, is tightly focused on two of South Australia's most important photonics markets. Like Photonics West, it balances a commercial exhibition with a scientific conference, and would provide an excellent forum for gathering market information and meeting potential customers, collaborators, students, and potential faculty members.

Conference on Lasers and Electro-Optics (CLEO)

Similar in size to DCS, but with a scope as broad as Photonics West, this 'roving' event is more academically focused, although it has a very small exhibition.

Australian Government-sponsored trade missions and programs

There are many international trade development programs available through the Australian Government. G'Day USA, which aspires to 'bring together leaders from government, business, the creative industries and academia to deepen the Australia-US relationship', is one example. G'Day USA events in 2022 of direct relevance to South Australian photonics include the Space Industries Exchange held in Colorado Springs, and the Defence Industries Dialogue held in Washington DC. In addition to increasing the visibility of South Australian photonics in the target country, events like these provide excellent opportunities for networking with experienced 'boots on the ground' Australian business development personnel in target countries. South Australian participation in such events should always highlight the photonics expertise of the state.

South Australia's unique areas of expertise in photonics have poised it to participate in numerous lucrative markets and to rise head and shoulders above other states in this dynamic and rapidly growing industry.

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