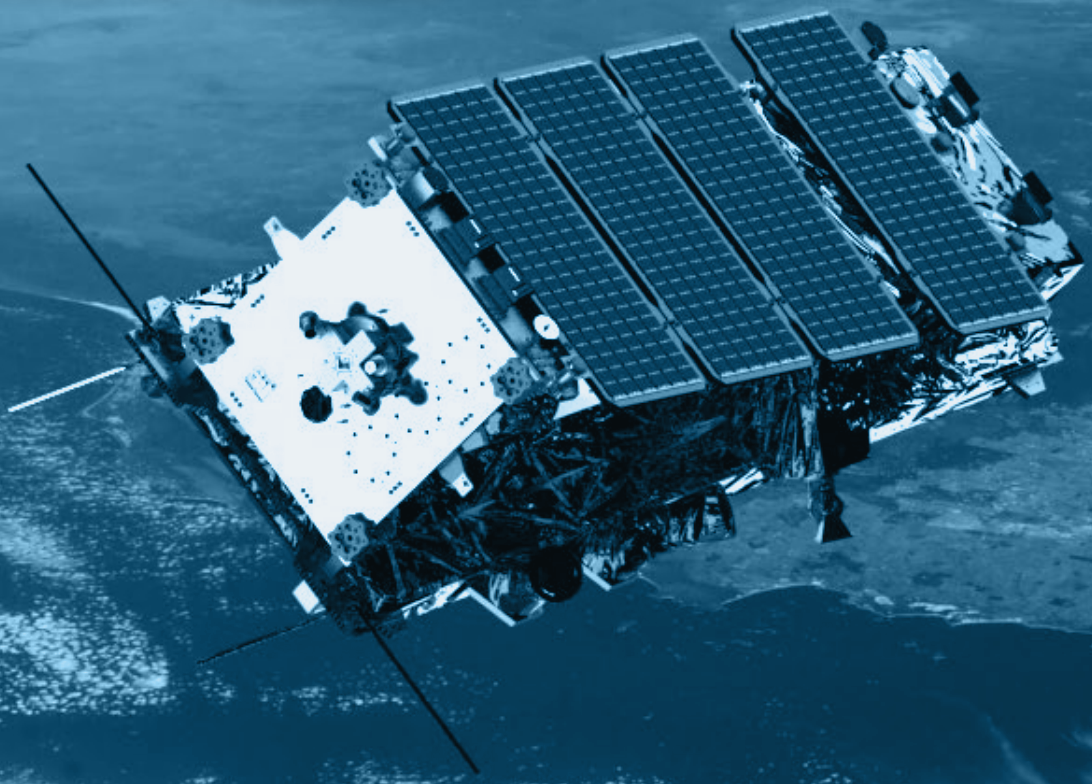
Space

A Roadmap for unlocking future growth opportunities for Australia

2018



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CSIRO Futures is the strategy advisory arm of Australia's national science agency

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CSIRO Futures is the strategy advisory arm of Australia's national science agency. We work with senior decision makers in Australia's largest companies and government to help them translate science into strategy and plan for an uncertain future. We build on CSIRO's deep research expertise to help our clients create sustainable growth and competitive advantage by harnessing science, technology and innovation.

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CSIRO Astronomy and Space Science develops and operates world-class National Facilities for radio astronomy and spacecraft tracking, and space-related technologies for the benefit of Australian and international science communities. We play a key role in the Square Kilometre Array project, Earth observation and sensor technology development, including commercialisation of innovative technologies and big data processing techniques.

CSIRO acknowledges the Traditional Owners of the lands that we live and work on across Australia and pays its respect to Elders past and present. CSIRO recognises that Aboriginal and Torres Strait Islander peoples have made, and will continue to make, extraordinary contributions to Australian life including in cultural, economic and scientific domains.

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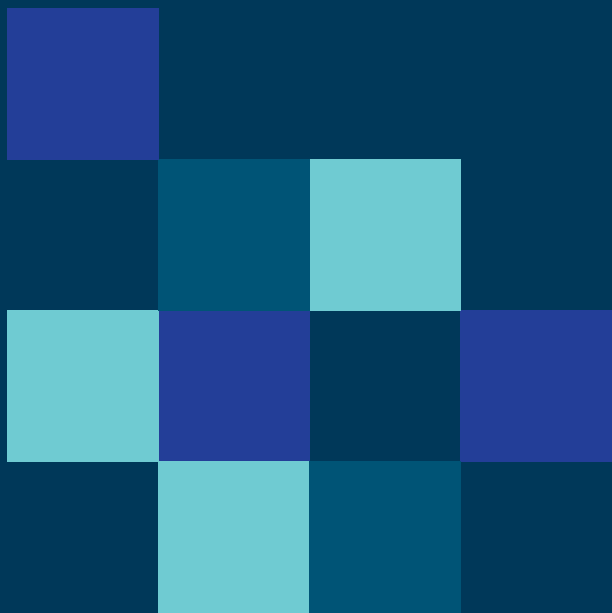


CSIRO Foreword

With Australia on the cusp of its own space age, CSIRO stands ready to draw on our 75 years of experience in the space sector to help launch Australia into a new era. In deep partnership with our newly formed Australian Space Agency, CSIRO's scientific, technical, industrial and regulatory expertise provide a firm foundation from which to propel future engagement and growth for the national space industry. CSIRO's Space Roadmap draws on our networks within the Australian space industry, helping to inform the strategic direction now being developed by the new space agency, setting out viable opportunities that can help launch Australia's space industry into a new era.

CSIRO's national footprint, together with our broad sector engagement, long track record in space science, and technical capability all underpin our deep commitment to the development and expansion of Australia's space industry. The creation of a dedicated space agency signals a new approach for the sector, providing Australia with a co-ordinated body to strengthen industry relationships and promote Australia's reputation as a dynamic and ambitious space-focused nation. In partnership with the agency, we look forward to transforming and growing a globally respected Australian space industry, opening up our markets, improving productivity, creating new jobs, and securing our STEM talent pipeline into the future.

CSIRO's role in the space ecosystem continues to broaden in response to rapid change in the global economy. The recent launch of our CSIRO Centre for Earth Observation provides a dedicated facility for satellite-derived data, including data gathered from our tasking and acquisition time on the NovaSAR satellite, the first time Australian scientists have ever been able to drive an imaging satellite. Our deep skill in managing and analysing big data, predictive analytics and Artificial Intelligence will drive new opportunities and approaches. Our global industry connections and long-standing partnerships with international space agencies are now also complemented by programs to support new domestic market entrants, including SME Connect, the ON accelerator program and the CSIRO Innovation Fund, managed by Main Sequence Ventures. And CSIRO's world-class space facilities and infrastructure build on Australia's unique geographical location and expansive land-mass to contribute to global infrastructure, like the Square Kilometre Array (SKA).

This Space Roadmap introduces opportunities for growth and differentiation based on Australia's natural advantages, and leveraging our established industries to repurpose for space – like new materials, mining to extract water, oxygen and inks to print spare parts, agriculture to grow food in inhospitable terrain, space object tracking, and space exploration and utilisation. It goes on to identify enablers for unlocking these opportunities. Deep collaboration between CSIRO, the Australian Space Agency, and partners in research, education, government, industry and investor communities will be critical. We are committed to continuing to grow a diverse and robust space industry in Australia, including bringing our world-class science, technical solutions, and partners to the table. We are here to help Australia secure our footprint in the space ecosystem.

Dr Larry Marshall
CSIRO Chief Executive

Australian Space Agency Foreword

It is my pleasure to endorse the CSIRO Space Industry Roadmap. As our national science agency, CSIRO brings many decades of scientific, technical, industrial and regulatory expertise and partnerships in the space industry. It is one of the inputs being used to inform the strategic direction of our Australian Space Agency. This Roadmap introduces some key scientific opportunities which Australia can utilise to drive engagement and growth across the space value chain. It also highlights opportunities to enter high-growth areas and strengthen Australia's expanding space industry.

The Agency has a mandate to triple the size of our domestic space industry up to $12 billion by 2030, generating 20,000 new Australian jobs, and inspiring our next generation of STEM professionals and entrepreneurs. Our purpose is to transform and grow a globally respected Australian space industry that lifts the broader economy and inspires Australia. It will be underpinned by strong national and international engagement.

CSIRO has a long and accomplished history in advanced research and technology in the fields of space sciences and space tracking, including Earth observation, remote sensing and data management.

I congratulate CSIRO on their Roadmap, which both supports the strategic intent of the Agency and clearly identifies both key opportunities and key enablers for future success. We have a compelling program ahead of us and I trust that this Roadmap will be a useful guide for those looking to invest and build Australia's space industry capability. I look forward to further analysis and engagement with specific opportunities to showcase Australia's capabilities to the world.

Together, the Australian Space Agency, CSIRO and other key partners will drive the full potential of our nation's capabilities and competitive advantages, optimising our research and development opportunities, and targeting growth areas across the space value chain to building a space sector of which all Australians can be proud.

Dr Megan Clark AC
Head, Australian Space Agency

Contents

1 Space for Australian growth

Profound transformation of space technologies alongside increasing demand for space-based services are driving the emergence of a new space age, and with it, many new opportunities for the growth of Australia's own space sector.

Space-based services are integral to the lives of Australians, national security and the operation of industries – transportation and logistics companies rely on positioning technologies to track their fleets; mining and resource industries use satellite imagery for exploration, to plan infrastructure, and conduct impact studies; and satellite communications play a key role in enabling improved connectivity for Australia's rural areas. And these are just a few examples.

While Australia's space industry is small in the global context, responsible for approximately 0.8% of the international space economy, Australian space science research is world class, contributing 6.8% of global publications between 2012-16.[1] Collaboration with leading international bodies along with new developments in the space field are creating opportunities for industry and business development that can provide greater economic return. Recent developments, both in the space ecosystem through the establishment of the Australian Space Agency, and pioneering technology transformation indicate that Australia's space industry has reached an inflection point and is poised for growth.

This report, developed through a process of consultation with industry and CSIRO's research expertise, seeks to support Australia's growing space industry by identifying opportunities across space-derived services, space object tracking, and space exploration and utilisation. These three strategic areas leverage Australia's comparative advantages and geography, and can provide benefits to other industries or value chains.

Vision: Over the next two decades, Australia's space industry will leverage the nation's unique strengths and advantages to increase its role in the international space sector, providing strategic contributions to global value chains that result in economic return and improve the lives of Australians.

To capitalise on these opportunities and position Australia as an active contributor to the international space industry, this report identifies a number of enablers that will help to unlock industry potential and guide research and development. Importantly, investment in space science and technology is a valuable source of innovation for Earth-based industries, bringing direct benefits to society. For example, key nutrients used in baby formula were originally developed for astronauts on long-duration, deep space missions.[2]

1 Finch A. and Wells X.E. (2017). *CSIRO Science Health and Excellence Report 2016-17, Full Version*. CSIRO, Australia

2 NASA (n.d.). *NASA Spinoff – Nutritional Products from Space Research*, [Online] Available from: https://spinoff.nasa.gov/spinoff1996/42.html, Accessed: 7/06/2018

WHY AUSTRALIA?

Nearly 50 years ago, Australia was a strategic partner in the US Apollo 11 Moon landing, receiving the first signals from the lunar surface. Since then, Australia has continued to refine its world-class capabilities in space-oriented fields, such as satellite and wireless communications, Earth observation data analytics, and advanced sensor and antenna technology for radio astronomy. These skills have seen the space industry play an important role in the broader economy, enabling innovation across other sectors including agriculture, environment, communications and mining. Today, the nation is in a favourable position to reinvigorate its commercial space industry with the 2018 Review of Australia's Space Industry Capability[3] (the Review) outlining an ambitious strategy to triple the size of Australia's space industry by 2030.

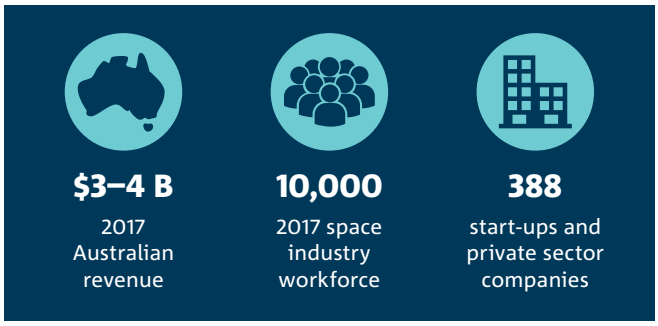
A key advantage driving Australia's space industry is the nation's strategic southern hemisphere location and land mass – characteristics that provide a 'sweet spot' for space related activities and allow for low light and electromagnetic interference. These attributes make Australia an attractive partner for integration into global value chains and provide advantages for development of positioning services and technology, Earth observation calibration, validation and data analytics, and space situational awareness activities.[4] Australia is also an advantageous location both for polar and equatorial launch sites. When considered together with Australia's skilled workforce and research expertise in complementary fields (agriculture, robotics, biomedicine, etc.), there are substantial opportunities for unique industry development and strategic collaboration in global value chains.[5]

While Australia's space related industry is relatively small, the Review outlines a series of recommendations that take advantage of Australia's current space industry structure, unhampered by legacy institutions. The Review's recommendations provide a base for the local space industry to leap past traditional space activities of other spacefaring nations and focus on high-value emerging technologies that return significant benefit to the economy. The establishment of the Australian Space Agency signals political support and creates momentum in the industry, placing Australia in a favourable position to capture commercial value from the global space sector.

The economic impacts of a strong local space industry are broad. Space services are already fueling the Australian economy, with growing downstream space applications stimulating innovation and the development of new industries. For example, convergence of Australia's expertise in agriculture and data analytics together with access to positioning and Earth observation data has enabled precision agricultural systems, allowing farmers to monitor and manage crops throughout a season, leading to new exportable solutions.

Additionally, access to globally competitive space capabilities is critical for Australian national security, law enforcement and to the safety of citizens during disasters.[6] Australia currently relies on strategic partners for access to space applications of national significance, which results in vulnerability to sudden geopolitical changes. Improving sovereign capability and growing Australia's industry will help to mitigate vulnerabilities.

AUSTRALIAN SPACE INDUSTRY SNAPSHOT



The space value chain is broad, covering upstream activities which focus on ground systems, launch and operating objects in space, together with downstream activities that utilise space data and technologies across a range of applications (Figure 1). Downstream activities will continue to expand as the role of the space industry in the broader economy grows.

3 Clark, M. *et al* (2018). *Review of Australia's Space Industry Capability - Report from the Expert Reference Group for the Review*.
4 Bryce Space and Technology, LLC (n.d.). *Global Space Industry Dynamics,* Department of Industry, Innovation and Science, Canberra.
5 ACIL ALLEN (2017). *Australian Space Industry Capability*, Department of Industry, Innovation and Science, Canberra.
6 Department of Industry, Innovation and Science (2017). *2017 State of Space Report*, Canberra.

Australia's space industry is estimated to have generated revenues of AU$3-4 billion in 2017, with a workforce of around 10,000.[7] Australia accounts for only a small proportion of the US$345 billion global industry,[8] but accelerating growth in the space sector and disruptive trends (see page 5) are creating opportunities for Australia to secure a greater share. Three quarters of the global space economy is attributable to commercial activities, predominantly from the satellite industry, with the remaining quarter coming from the budgets of over 50 national governments, nine of which exceed US$1 billion each.[9]

Within Australia, over 388 start-ups and private companies are part of the space sector, particularly in downstream space-enabled services and ground systems.[10,11] Space-related research, development and education and training is supported by a number of Australian universities, Cooperative Research Centres and publicly funded research agencies. These include the Advanced Instrumentation and Technology Centre at ANU, UNSW's Canberra Space Centre and Australian Centre for Space Engineering Research (ACSER), the Space Environment Research Centre (SERC), Geoscience Australia, CSIRO, and many others. The Australian Space Agency will grow and transform the Australian space industry and play an important role in developing the national space innovation ecosystem.

FIGURE 1: THE SPACE VALUE CHAIN[12]

7 ACIL ALLEN (2017). *Australian Space Industry Capability*, Department of Industry, Innovation and Science, Canberra.
8 Bryce Space and Technology, LLC (n.d.). *Global Space Industry Dynamics,* Department of Industry, Innovation and Science, Canberra.
9 Bryce Space and Technology, LLC (n.d.). *Global Space Industry Dynamics,* Department of Industry, Innovation and Science, Canberra.
10 ACIL ALLEN (2017). *Australian Space Industry Capability*, Department of Industry, Innovation and Science, Canberra.
11 Asia Pacific Aerospace Consultants (2015). *A selective review of Australian Space Capabilities: Growth opportunities in global supply chains and space enabled services*, p.33.
12 Clark, M. et al (2017). *Review of Australia's Space Industry Capability, Issues paper - August 2017*, Australian Government, [Online] Available from: https://industry.gov.au/industry/IndustrySectors/space/Documents/Review-of-Australias-Space-Industry-Capability-Issues-Paper.pdf Accessed: 6/06/2018

TRENDS DRIVING GLOBAL GROWTH

FIGURE 2: SPACE INDUSTRY TRENDS

1. Technology transformation

Profound technology transformation is driving significant changes in the space domain. 'Space 2.0' is changing the industry, based on the introduction of miniaturised, low cost technologies, and more sustainable and reusable systems, with improved power and propulsion on the horizon. Convergence with advances in high-performance computing, materials, robotics, and increased data exchange, including through artificial intelligence and advanced analytics will continue to push transformation.

6. Game changers

The next frontiers of the space industry are opening up, including space-based tourism, energy, manufacturing, asteroid mining, deep space missions and living 'off-world' in closed-loop systems. Innovative space technologies, services and business models will be game changing to the space industry, but also transformative to on-Earth industries through diffusion of innovations into everyday life. Completely new disruptive industries will be enabled, such as 'data-mining' industries that derive value from space data.

2. Developing downstream

Innovation at the downstream end of the space value chain has led to an expansion of the applications for space-derived data and services, leading to new businesses, new industries and new ways to solve grand challenges. Examples include precision agriculture, environmental management from forests to reefs, mining, and many more. Developing downstream markets is driving demand for the upstream space industry.

5. Conflict and vulnerability

With nations and industries heavily reliant on space, especially for critical infrastructure, security and military applications, any disruption could prove devastating. The possibility of conflict in outer space is growing,[13] as are vulnerabilities related to cyber-attacks. Access to previously free and open data from global Earth observing satellites could be diminished due to sovereignty considerations, or as nations move to recover their investment in public assets. This presents challenges, but also opportunities for development of Australian capabilities and industry growth.

3. Accessible space

Innovation and new technologies are enabling more commercial applications of space through miniaturised satellites, reusable rockets, lowering launch costs and distributed ownership of space assets. Increased private investment and commercialisation of space means it is no longer a place just for governments and large organisations, but also small companies and entrepreneurs. Civilian spaceflight is being developed by a number of entrepreneurial ventures.

4. Increased data exchange

Globally, the volume of data generated daily is increasing, driven by increased sensorisation and digitalisation across industries, governments and households. Data derived from space provides a unique view not available from other sources. Data exchange and associated Big Data analytics are creating significant value across industries. When used intelligently, the larger variety, access speed, and volumes of data from space-based platforms allow for more informed decision-making and increased productivity. This will require a step-change in data analysis techniques including artificial intelligence, machine learning and on-board processing.

13 University of Adelaide (2018). *The Woomera Manual on the international law of military space operations*, [Online] Available from: https://law.adelaide.edu.au/military-law-ethics/woomera/Woomera_Manual.pdf Accessed: 06/06/2018

2 Opportunities for growth

Australia currently has an opportunity to grow its space industry, not only the upstream, through encouraging innovation in space- and ground-based systems, but also the downstream industry, by developing new services, businesses and industries based on space-enabled data and services. Through consultation with industry, including numerous interviews with companies in the sector and feedback through CSIRO's Space 2.0 Workshop, three broad areas of opportunity for Australia's future in this sector have been identified (Figure 3):

- **Space-derived services** – using space data and satellite communications to grow downstream commercial applications, for example, the use of Earth observation data for a vast range of services such as remote asset management, and environmental monitoring and assessment.
- **Space object tracking** – leveraging Australia's unique geographic position to nurture commercial opportunities for tracking and monitoring space objects to reduce the risk of collision and consequent damage to space infrastructure, as well as spacecraft communication services.
- **Space exploration and utilisation** – building on Australia's strengths across different industries to apply new technologies and systems to the challenges of robotic and human space exploration.

While this report is informed by industry consultation, the opportunities identified are consistent with the priorities of the Australian Space Agency. They leverage the nation's capabilities and advantages, and are aspirational and powerful, enticing public interest and requiring widespread collaboration to achieve success. Similar to the Innovation and Science Australia (ISA) concept of National Missions,[14] growing Australia's space industry, and in particular, developing new innovations for space exploration, will challenge, inspire and drive an innovative culture and ambition. Collaborating to develop new technologies and businesses will demonstrate to the world that Australia can deliver breakthrough innovation.

Each opportunity is described within this section, outlining potential developments over the short to long term, and a future scenario that highlights how the opportunity may be developed in the Australian ecosystem.

FIGURE 3: KEY OPPORTUNITIES FOR GROWTH

14 Innovation and Science Australia (2017). *Australia 2030: prosperity through innovation*, Australian Government, Canberra.

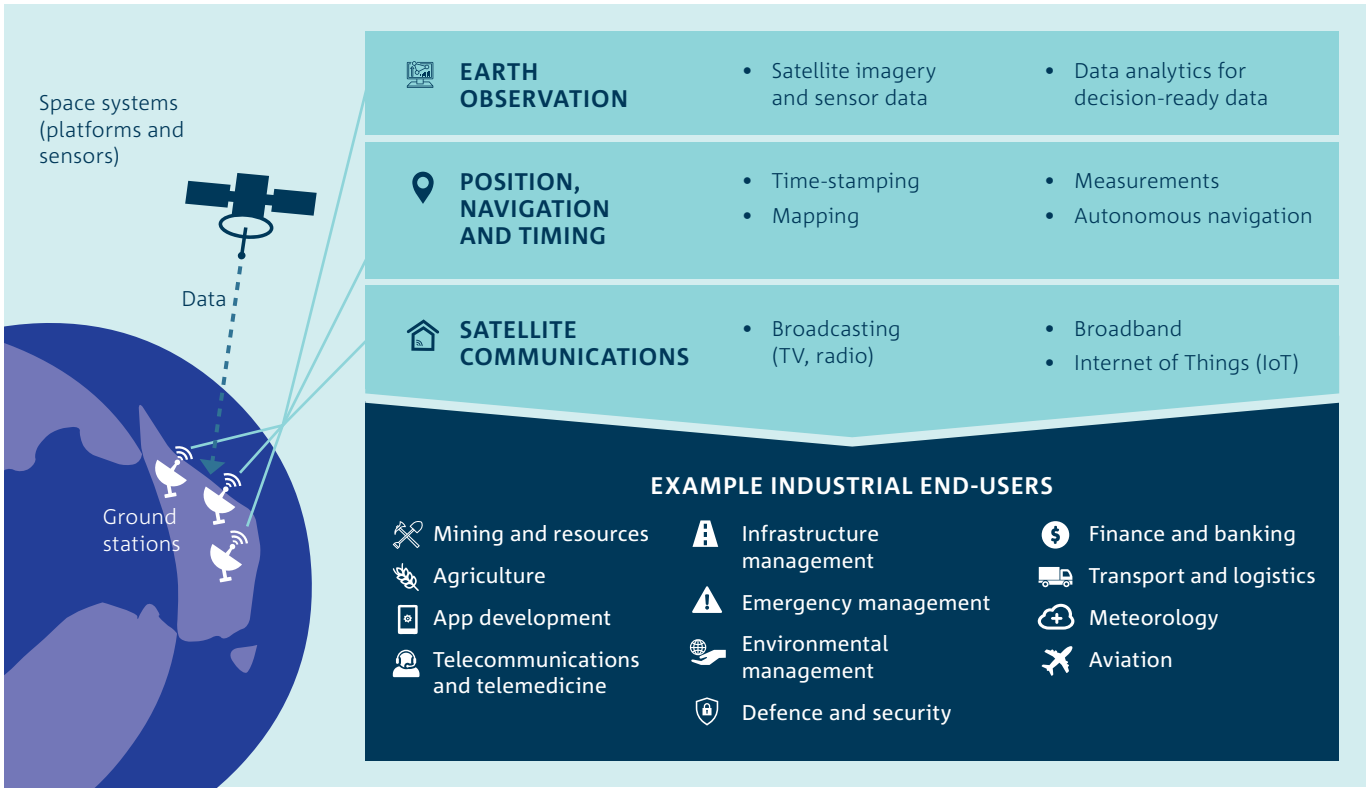
2.1 Space-derived services

Growing the ecosystem and downstream utilisation of space-derived data and services

Space-derived data and services such as Earth Observations from Space (EOS), Position, Navigation and Timing (PNT) and satellite communications are increasingly being used by Australian businesses and government to improve productivity, innovation and inform strategic decision making. These three key applications are recognised as areas of priority by the Australian Space Agency,[15] and developing new value-added services derived from these applications could result in significant additional economic benefit to existing and new industrial end-users. For example, satellite imagery and accurate positioning services are enabling the development of precision agriculture methods, with reports estimating that the value of Australian satellite imagery-enabled precision farming for broad acre cropping could reach $221 million annually by 2025, up from $17 million in 2015.[16] Space-derived services and related technologies also improve the Australian way of life through the provision of more accurate satellite navigation, satellite TV services, internet access enabling telemedicine services for rural communities, nation-wide weather forecasts and disaster monitoring.

Australia is well placed to develop advanced capabilities, platforms and new businesses that deliver decision-ready data and value-added services based on EOS and PNT data to a range of Australian and export industries. This will help to meet growing downstream demand (Figure 4). Australia is one of the largest consumers of EOS data, and with its strong research capability and data analytics solutions, has developed unique methods for space-based observation which are already being implemented in other countries.

FIGURE 4: OPPORTUNITIES FOR SPACE-DERIVED SERVICES



15 Australian Government (2018). *Australian Space Agency*, [Online] Available from: http://www.space.gov.au Accessed: 10/07/2018

16 ACIL ALLEN (2015). *The Value of Earth Observations from Space to Australia,* CRC for Spatial Information.

While foreign businesses can provide similar services, Australia's unique landscapes and remote primary industries require customised solutions for EOS and connecting distributed and rural population centres. Australia's heavy reliance on foreign-owned satellites for access to data[17] presents a risk to continuity of supply. However, there is an associated opportunity to develop Australian infrastructure, products and services such as advanced data analytics and data fusion products.

This opportunity is enhanced by the emerging Space 2.0 paradigm of miniaturised and cost-efficient space technologies, which is enabling a similar shift in the availability of space-derived data for input into industry. As new sensors, positioning and communications platforms become available, so too will broader and more valuable services. Concentrated effort and support towards growing the Australian space data services ecosystem will leverage Australia's research strengths, especially in data analytics and computation, and will contribute to building up the nation's industrial strengths. Examples include agriculture and forestry; mining and mine waste solutions; and managing extreme weather events.

INDUSTRY OPPORTUNITIES

Table 1 (page 10) identifies industry opportunities and developments expected over the short to long term for space-derived services. Each of these application areas will be driven by rapid technological advancement in satellite technologies including miniaturisation, all-electric systems, component and sensor development, and new downstream applications.

AUSTRALIA IN THE 2030s: EARTH OBSERVATION FOR EFFICIENT WATER MANAGEMENT

It is the mid-2030s – Australia has world-leading water management and water trading practices supported by bespoke monitoring technologies and based on the integration of hydrologic models, high-performance Earth observation data analytics and space-enabled ground sensor networks.

Australia remains the driest inhabited continent on Earth with water resource shortages, land-use issues and population growth continuing to put pressure on the country's agriculture industry and unique ecosystems. However, the 2030s has seen application of best-practice agriculture methods such as precision farming and water resource management which have helped to relieve this pressure while at the same time increasing agricultural yield from an average 50% of total potential yield in 2016 to over 80% across major food producing regions.[18] This production growth has cemented Australia's global position as a quality food exporter, especially to Asian countries, and has been enabled by the growth of Australia's space-derived services such as EOS, accurate positioning and widespread digital communications.

17 CRC for Spatial Information (2016). *Australian Government Earth Observation Data Requirements to 2025*, Geoscience Australia and Bureau of Meteorology.
18 Hochman, Z., Gobbett, D., Horan, H., & Navarro Garcia, J. (2016). *Data rich yield gap analysis of wheat in Australia*, Field Crops Research, 197, p97-106.

Water is now managed and tracked with high accuracy to ensure optimal usage, while also ensuring the health of Australia's unique ecosystems. Australian companies have developed scalable platforms that integrate hydrologic models and data from a range of modern satellite-based Earth observation data streams and ground-based sensors, delivering actionable information on Australia's water resources, their water quality, quantity and related demand, in high resolution and real time (Figure 5). Nation-wide indicators such as precipitation, soil moisture, bushfire fuel loads, water storage, quality, use and wastage are regularly monitored, with Australian-produced satellites and payloads delivering Australian-specific data and security of data supply.

A precise picture of the water system across different water basins is available, including inflows and outflows, demand, stress, plant vigor, crop water usage, waste, quality (e.g. algal blooms), flood drought and fire risk. This allows for optimised targeting of water to maintain environmental standards and optimal productivity.

Availability of this information allows decision makers including farmers and water management authorities to precisely monitor their water resources. In the Murray-Darling Basin, these tools have enabled farmers and authorities to maintain a precise balance between environmental flows and irrigation, resulting in vast increases in total production. Numerous data streams are converted into decision-ready information by water managers and Australian companies, providing insights that are directly useable by end-users.

Australia's unique challenges mean that no single foreign product meets the needs of Australian producers. This has seen Australia nurture world-class capability and has also led to new exports, with foreign countries recognising Australia's world-leading water management practices and technologies. With a significant proportion of the world's population under water stress, Australian technology for water resource management, underpinned by space-derived services, is recognised for its critical role in global sustainable development.

FIGURE 5: AUSTRALIA IN THE 2030s – EARTH OBSERVATION FOR EFFICIENT WATER MANAGEMENT

TABLE 1: SHORT TO LONG TERM POTENTIAL INDUSTRY DEVELOPMENTS AND OPPORTUNITIES FOR AUSTRALIA

	SHORT TERM (1-5 YEARS)	MEDIUM TO LONG TERM (5-10+ YEARS)
Earth Observation from Space		
EOS data provides regular observations of Earth's physical, chemical and biological systems over large geographic areas and extended periods of time. The value and demand for this data is increasing as it becomes a critical input for governments and industry alike. Developments in the variety, resolution and timeliness of EOS data will expand its applications for different end-users. Examples include: aquaculture, environmental monitoring of pollution, water quality and quantity, ocean and atmospheric conditions, biodiversity etc., and monitoring of illegal activities such as clearing, fishing, smuggling.	• Robust service ecosystem for customised decision-ready data for end-users, e.g. agriculture, mining, defence, ports, the Great Barrier Reef, urban planning etc. • Artificial intelligence and machine learning analytical programs enabling greater situation monitoring and decision support tools • Next-generation satellite technologies including small satellite constellations operating in concert, new power and data management systems, field programmable gate arrays (FPGAs) and ground link systems • Scalable data platforms and protocols • Integration of multi-sensor data streams for improved monitoring • Automated super sites and vicarious calibration services for global small satellite constellations • High altitude and in-orbit platforms for high resolution radar and hyperspectral imaging • On-board data processing to optimise data transfer • Fusion of EOS and PNT data for more precise observations	• Commercial service providers covering all points at all times, providing improved optical and temporal resolution • Constellations and mother satellites with less reliance on distributed ground stations • Real-time decision-ready data and services available via mobile smart devices • High resolution, real-time full motion video observations • Next generation space-based sensors that enhance functionality via greater resolution and revisit rates • Linking atmospheric effects on population health and providing monitoring and early warning services
Position, Navigation and Timing		
Access to accurate and real-time PNT data is an integral part of business operations across many industries, helping to manage fleets of vehicles, improve regulation of air traffic and shipping, provide time-stamping, etc. PNT improvements will enable new innovations and business models using location-based services.	• Enhanced positioning using ground-based augmentation systems and the National Positioning Infrastructure • Centimetre accuracy for lateral positioning technologies • Improved availability of positioning services in urban canyons and rural areas • Improved accuracy in vertical positioning • New applications and devices that utilise satellite-based augmentation systems and exploit Australia's unique multi-GNSS location	• Improved precision timing to allow for better positional accuracy and increased network data rates • Quantum cyber security solutions to protect against spoofing • End-user devices and applications including advanced robotics and smart transportation networks
Satellite Communications		
Satellite services are a growing part of global communications infrastructure, enabling high-speed access to information including TV broadcasts and broadband internet services.	• Tbps-scale data transfer speeds using Ka band devices • Satellite radio • Satellite-enabled Internet of Things, improving availability in rural areas • Higher frequency satellite communications, including laser	• Small satellite constellations for ubiquitous high-speed broadband • Unconditionally secure in-space and space-ground quantum communications including Quantum Key Distribution and bright-light optical systems • Deep space optical communications

2.2 Space object tracking

Building an Australian industry to track space objects, ensuring continued availability of space assets

The global economy is dependent on the uninterrupted availability of space infrastructure. Endangering this is a growing orbital congestion issue, driving the need for accurate and comprehensive tracking and identification of orbiting objects, and improved communication with objects (spacecraft) in deep space. Collision of orbital objects/debris presents a risk with cascading effect, increasing the vulnerability of space-based assets which could also ultimately deny access to space. Space objects that need to be tracked include operational and retired spacecraft in orbit, and increasing amounts of space debris (the US Joint Space Operations Centre actively tracks 23,000 large objects[19] of the estimated 750,000 manmade objects in orbit[20]), as well as operational spacecraft communicating with Earth from deep space, and natural Near Earth Objects such as asteroids and comets.

Australia has a unique opportunity to develop its commercial industry for tracking space objects and deep space communication. The nation plays a strategic role as a key node in the global industry due to its geographic location which allows monitoring of parts of the sky that cannot be monitored from the northern hemisphere. Australia also has low light and radio noise interference, and ground stations connected over vast distances that can provide improved real-time temporal resolution.

These unique advantages have already triggered collaborations with major space agencies, such as the European Space Agency's New Norcia Deep Space Antenna near Perth, NASA's Canberra Deep Space Communication Complex, and the recent relocation of the US C-Band Space Surveillance Radar System to the Harold E. Holt Naval Communication Station in Western Australia. Australia has an opportunity to expand this role as the US enacts Space Policy Directive-3 on Space Traffic Management which calls for greater data sharing and international collaboration.

19 Liou, J.C. (2016). *The orbital debris problem,* presented at Space Tech Conference, Pasadena, California, [Online] Available from: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160005242.pdf Accessed: 6/06/2018

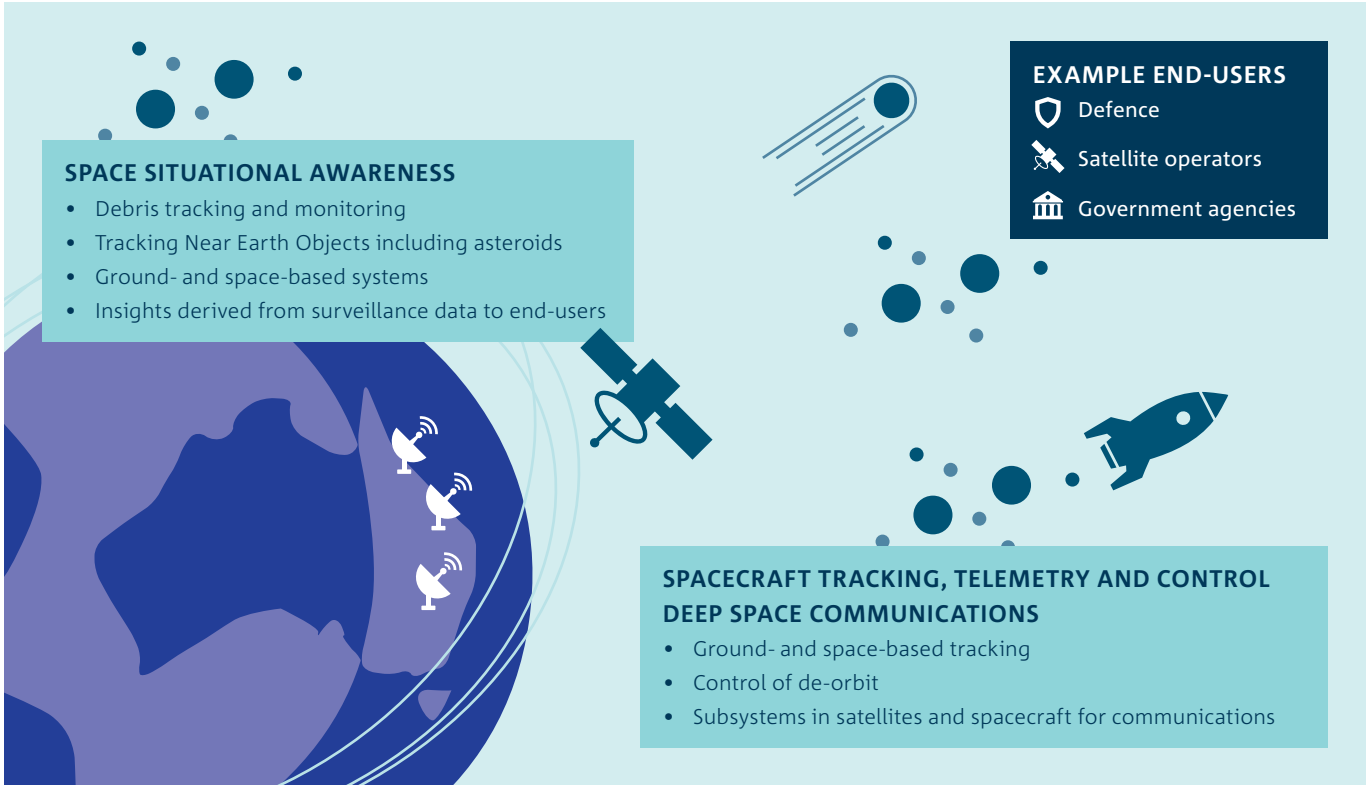
20 European Space Agency (2017). *Space operations, Space debris: the ESA approach*, [Online] Available from: https://download.esa.int/esoc/downloads/BR-336_Space_Debris_WEB.pdf Accessed: 06/06/2018

Tracking space objects involves the use of ground-based space surveillance sensors, typically comprising radar, radio telescopes and laser-ranging stations. Space situational awareness (SSA) is an activity that is evolving rapidly, increasingly moving into the commercial sector after long being exclusively a government function. Tracking the orbits of objects allows operators from government and industry to predict and take action to avoid collisions. These operators will require deep SSA data sharing, integration of systems together with advanced analytics. Over the long term, tracking space objects together with advancements in propulsion, robotics and analytics will enable the active removal of debris through robotic arms, nets, laser ablation, harpoons and tethers.

Tracking, telemetry and control (TT&C) of spacecraft and communication with deep space probes through Direct to Earth systems or relay satellites is essential to enabling greater space exploration. According to NASA, deep space communications capability will need to grow by nearly a factor of 10 in each of the next three decades.[21]

The market for this opportunity includes Defence and relevant civil authorities, where the protection of space assets is necessary to protect against disruptions that may endanger life, and commercial users, where disruption of satellite operations may lead to loss of revenue (Figure 6). SSA is also imperative to companies pioneering space tourism and is a bridge to greater in-orbit capabilities including servicing satellites and resource utilisation.

FIGURE 6: OPPORTUNITIES FOR SPACE OBJECT TRACKING



21 NASA Jet Propulsion Laboratory (n.d.). *Deep Space Communications*, [Online] Available from: https://scienceandtechnology.jpl.nasa.gov/research/research-topics-list/communications-computing-software/deep-space-communications Accessed: 06/06/2018

INDUSTRY OPPORTUNITIES

TABLE 2: SHORT TO LONG TERM POTENTIAL INDUSTRY DEVELOPMENTS AND OPPORTUNITIES FOR AUSTRALIA

	SHORT TO MEDIUM TERM (1-10 YEARS)	LONG TERM (10+ YEARS)
Space situational awareness – tracking near Earth objects and debris		
As the space industry grows and more activity occurs, the space environment will become more congested and more space debris will be created. This drives the need to track the orbits of debris and objects, develop measures to mitigate and clean-up debris, and protect vital space infrastructure from collision.	• Australia plays an active role in a global SSA network and traffic management • New services based on shared access to infrastructure driving commercial SSA – including asteroid tracking, and conjunction mitigation-as-a-service • Improved ground-based systems for more accurate tracking of small debris • On-board satellite anti-collision sensors and autonomous mitigation programs • Artificial intelligence for improved SSA	• Accurate in-space tracking of all space debris down to sub-cm size orbiting Earth • In-space situational awareness using a range of small-to-large satellites • Active debris removal and decommissioning of end-of-life satellites, potentially through robotic attachments, tethers, in-orbit recycling • Autonomous in-orbit servicing • Expanded space situational awareness programs to map resources in space
Spacecraft tracking, telemetry and control, and deep space communication		
Tracking, telemetry and control (TT&C) of spacecraft is an important function enabling growth in the space industry. TT&C requires ground stations and networks and will need improved speed, bandwidth and fine control of manned, autonomous and semi-autonomous systems. Innovation in deep space communication is required to meet the increasing challenges and demands driven by space exploration.	• Advanced sensors and instruments for deep space missions • Low-bandwidth, low-latency communication systems for autonomous spacecraft • Disruption Tolerant Networking (DTN) for internetworking of space missions • Passive on-board de-orbiting capabilities • Low cost off-the-shelf avionics systems for small spacecraft • Greater co-ordination of ground station assets in Australia • Deep space positioning and navigation using stars and pulsar X-rays	• Hybrid optical/radio high bandwidth deep space communications • Observing constellations around distant planets communicating via hybrid receivers and geostationary gateways • Ground stations in higher latitudes including Tasmanian and Antarctic locations for monitoring polar orbits • On-board autonomous navigation and manoeuvring • Active beacons and transponders added to space components for tracking, modelling and forecasting trajectories of debris

AUSTRALIA IN THE 2030s:
A TRUSTED PARTNER FOR SPACE SITUATIONAL AWARENESS

It is the mid-2030s – Australia is home to a growing space situational awareness industry that is a trusted partner to many international companies and agencies for the provision of tracking, control and conjunction mitigation services, and planetary defence.

Over the past decade, space has become increasingly congested, contested and competitive, with large numbers of satellite constellations, debris and increasingly, tourists. To address this, Australia has built on its strategic geographic location in the southern hemisphere to develop its SSA industry, which provides commercial services and helps improve the sovereign security of Australia's defence and civilian assets. Australia, as a trusted partner to nations including Canada, New Zealand, the United Kingdom and the United States, has continued to receive investments through international partnerships with the Australian Space Agency and CSIRO, which have supported the development of a network of monitoring and control stations across the country. This has helped Australian companies to develop world-leading expertise in the design and operation of ground stations and their components, and the analysis of SSA data.

Australia's SSA industry encompasses many commercial companies that provide services to both Australian and international operators of space-based assets, such as satellite telecommunications, satellite constellations, space tourism ventures, and international networks for planetary defence. SSA growth has been supported by commercial access to data and tracking infrastructure and international systems integration and data sharing agreements.

A thriving Australian research and commercial ecosystem has exploited leadership in operating distributed, low-power networks across Australia's vast landscapes, which has led to in-orbit technologies for SSA and communications. Ingenuity of Australian companies and researchers has resulted in innovative solutions for disruption-tolerant systems with advanced analytical tools, such as artificial intelligence and machine learning improving Australia's ability to provide SSA and modelling. Further, the industry has pioneered the next generation of SSA, taking advantage of orbiting platforms that incorporate active interception of retired satellites and space debris. Research has also continued to break ground in developing networked constellations of small satellites, communicating with each other and with single ground stations through the use of mother satellites. These platforms also serve for earlier identification and characterisation of asteroids from their vantage point in orbit, in conjunction with ground-based telescopes.

Together, this has resulted in Australia becoming a trusted international partner for the tracking and monitoring of space objects from the ground and in space. Leveraging this capability in mapping orbital space and operating in-orbit and deep space missions has supported the development of research and commercial opportunities for Australia's resource sector to extend its domain into space. Resource assessments combined with a progressive investment-friendly regulatory environment provide Australian resource companies with a competitive start at the dawn of the space resource age.

FIGURE 7: AUSTRALIA IN THE 2030s – AUSTRALIA IS A TRUSTED PARTNER FOR SPACE SITUATIONAL AWARENESS

2.3 Space exploration and utilisation

Inspirational opportunities and cutting edge technology for wider Australian benefit

The International Space Exploration Coordination Group (ISECG), which brings together numerous international space agencies and research organisations (including CSIRO), has a coordinated vision to expand human exploration and presence in low Earth orbit, the Moon and on Mars over the next two decades. To do this, ISECG recognises that public-private partnerships are key, enabling access to innovation and collaborative development of full-scale prototypes and concepts. NASA's budget supports this vision with investment in deep space exploration systems and related research expected to reach $5.5 billion in 2019.[22] Exploration missions will first be robotic, followed then by human missions, with the aim of characterising new environments. Human space exploration and utilisation will be enabled by the planned development of an international deep space gateway – a small facility in permanent orbit around the Moon facilitating regular access to the lunar surface and as a gateway to Mars and beyond.

Australian businesses and research organisations are well placed to become valued contributors to global value chains for systems/technologies needed to meet these exploration goals and utilise space for Earth-based industries. To do this, industry must leverage Australia's diverse industrial and research strengths across areas such as astronomy, mining, manufacturing, medicine, agriculture, robotics, etc., together with Australia's already established alliances with international space agencies, including the US. Momentum created by a government-supported space innovation ecosystem needs to be embraced to grow Australia's industry and build the bold transdisciplinary collaborations needed to develop exploration technologies, which include spacecraft, habitats and supporting technologies to safely conduct robotic and human missions. This momentum is also expected to catalyse the development of other Australian industries, in particular, robotics.[23]

Developing niche technologies for global value chains will see growth in both traditional space businesses and non-traditional industries, and play an important role in building Australia's space industry and global reputation. Australia's globally competitive capabilities across many diverse fields can be leveraged by progressive space businesses to create the innovations required to support the ISECG's vision. For example, strengths in mineral resources and advanced manufacturing can be used to develop in-situ resource utilisation technologies; strengths in food, agriculture, medicine and remote asset management to develop habitat and life support systems; strengths in energy systems to improve power and propulsion; and strengths in robotics and sensors to develop autonomous systems (Figure 8).

Science and technology developed or refined for space exploration can be applied to industries on Earth, bringing direct benefits to society. For example, WiFi was developed as a result of Australian research in radio astronomy, and digital medical imaging was derived from initial efforts to image the Moon's surface.[24]

22 NASA (n.d.). *FY 2019 Budget Estimates*, [Online] Available from: https://www.nasa.gov/sites/default/files/atoms/files/nasa_fy_2019_budget_overview.pdf Accessed: 06/06/2018

23 Australian Centre for Robotic Vision (2018). *A Robotics Roadmap for Australia.*

24 Space Foundation (n.d.). *Digital Image Processing – Medical Applications,* [Online] Available from: https://www.spacefoundation.org/what-we-do/space-technology-hall-fame/inducted-technologies/digital-image-processing-medical Accessed: 16/06/2018

INDUSTRY OPPORTUNITIES

TABLE 3: SHORT TO LONG TERM POTENTIAL INDUSTRY DEVELOPMENTS AND OPPORTUNITIES FOR AUSTRALIA

	SHORT TO MEDIUM TERM (1-10 YEARS)	LONG TERM (10+ YEARS)
In-situ resource utilisation		
In-situ resource utilisation involves characterising and using local resources at the exploration destination to reduce space freight cost and logistical complexity involved in bringing required materials from Earth.	• Integration of ground stations to augment and support emerging space-based systems for advanced resource identification and mapping • Testing and characterisation of returned resource samples • Re-engineering mineral processing for lunar conditions • Teleoperation technologies for lunar in-situ resource utilisation • Characterisation of Near Earth Asteroids	• In-situ testing, analysis and characterisation of resources • In-space manufacturing, including 3D printing with local materials including metals and glass • Hydrolysis and methanation for in-situ fuel production • Closed loop carbon cycle including synthetic biology-based gas fermentation
Habitat and life support		
Missions with long durations will require innovative systems for long-term settlement in space, including habitation and life support. This involves all aspects of food, medicine and shelter.	• Inflatable space habitats • Teleoperation of space systems • Stabilised nutritionally complete food options • Support systems for water and waste recycling towards a closed loop habitat • Integrated telehealth and biomedical solutions for human space travel including advanced wearable technologies and in-vitro diagnostic devices to monitor crew health • Multipurpose flexible pressure suits and portable life support systems	• Oxygen recovery and air revitalisation technologies • Deep space habitats to support human missions • 3D printed systems for space habitation • In-situ food production • Bioremediation of soils on Mars (including toxic perchlorate compounds) • Precision health and nutrition for astronauts including synthetic biology manufacturing systems for medicine/ nutrition solutions, tested using organoid models (human tissue on a chip) to understand the impact of space on tissue physiology
Autonomous systems		
Autonomous robotic missions are an essential precursor and partner to human missions, able to venture into hostile environments to gather information and make human exploration safer. All space systems will become increasingly reliant on embedded analytics and autonomy.	• Fully autonomous landers capable of persistent and competent autonomy • Advanced mapping and sensing technologies • Multi-tasking flexible humanoid robots and assistive exoskeleton structures • AR/VR control and assistance • Robots for improved habitation and wellbeing • Advanced cyber security for autonomous systems • Advanced embedded quality assurance/control systems to verify the quality of engineering and science data during missions	• Teleoperation for lunar missions including resource extraction and full competent autonomy for deep space missions • Autonomous rendezvous and docking systems including imaging and minimum distance separation • Maintenance robots to prepare and maintain deep space sites prior to human presence • Semi- and fully autonomous robots for extra-terrestrial work including sensing, data processing and physical tasks
Power and propulsion		
Technology solutions for in-situ power generation, rocket engines and in-space propulsion.	• Reusable rockets and space systems • Printed lightweight flexible solar photovoltaics • Electrical satellite propulsion on commercial satellites • Technologies to convert wastes to power • Hybrid energy storage technologies • Thermoelectric generators including nuclear and solar materials • High power solar electric propulsion • Light/ultralight materials for rockets and payloads	• Autonomous modular power systems sent to deep space ahead of human exploration • Microthrusters including Microfluidic Electrospray Propulsion (MEP) • Space launch system for human spaceflight to deep space • Small-scale fission reactors • In-space concentrated solar thermal • In-situ hydrogen fuel production and on-site power generation systems

FIGURE 8: OPPORTUNITIES FOR SPACE EXPLORATION AND UTILISATION

POWER AND PROPULSION

- Printable solar photovoltaics
- Energy harvesting and storage
- Telemetry and vector control
- Fuels and catalyst design

HABITAT AND LIFE SUPPORT

- Deep space habitation
- Radiation shielding
- Telehealth and wearables
- Stabilised food and food production
- Recycling wastes

IN-SITU RESOURCE UTILISATION

- Processing new novel minerals and materials
- Additive manufacturing
- Resource mapping and prospecting

AUTONOMOUS SYSTEMS

- Distributed smart sensor networks
- Augmented and Virtual Reality (AR/VR) and teleoperation
- AI and machine learning
- Autonomous robotic systems

EXAMPLE END-USERS

- Government space agencies
- Technology transfer into industry (e.g. mining, health, food, etc.)

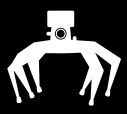
AUSTRALIA IN THE 2030s:
LUNAR HABITATS FEATURING AUSTRALIAN TECHNOLOGIES

It is the mid-2030s – World-class Australian skills and technologies are contributing to international exploration and colonisation efforts across many specialised areas.

Ambition and curiosity have driven the quest for space exploration with multiple public and private rockets transporting humans into lunar orbit, making the first steps towards becoming a multi-planetary species. The Lunar Orbital Platform Gateway, developed during the 2020s, provides a staging post for lunar surface shuttles and is preparing to send human missions to Mars. Collaborative exploration missions have mapped the far side of the Moon yielding the first comprehensive resource assessments, and Australian scientists, engineers and astronauts, in partnership with a diverse international community, are using the Gateway to colonise the lunar environment.

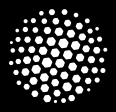
Australia's space industry has been an invaluable source of technologies and partners for the development of the first lunar habitat, and continues to develop technologies for the first Martian explorers, who will face at least 150 days of travel in deep space and a hostile environment upon their arrival. Many developments for space have now diffused into everyday life, and many Earth-based technologies have been spun in to the space industry.

FIGURE 9: AUSTRALIA IN THE 2030s – LUNAR HABITATS FEATURING AUSTRALIAN TECHNOLOGIES



Autonomous robots (e.g. legged robots) fitted with Simultaneous Localisation and Mapping (SLAM) and 3D laser scanning technology are used to accurately map lunar lava tubes for habitation and protection from cosmic radiation. Integrating data from numerous sensors produces highly accurate models of the lunar environment, helping to identify resources, threats and prospective development sites before extensive human arrival.

In-situ resource extraction and utilisation is enabled by semi-autonomous 3D printers operated alongside human-in-the-loop excavation systems that transform raw lunar regolith into building structures. For example, lunar soil rich in silica is formed into iron-rich glass for working surfaces and as lining and protective structures for underground habitats.



Australian synthetic biology research has contributed to continuous flow bioreactors using custom-designed organisms to remove carbon dioxide from the air within lunar habitats. Using gas fermentation, carbon is processed to produce macronutrients for food, as well as for use in metallic 3D printing, where in-situ titanium oxide and anorthite are reduced to titanium and aluminium. Oxygen released during processing is used to provide breathable air for a permanent human presence, and combined with hydrogen produced from hydrolysis of polar ice for rocket fuel.

Instead of being transported from Earth, lightweight flexible solar cells are increasingly printed by Moon-based systems using material recycled from retired satellites and space debris. As the demand for power grows, next-generation nuclear reactors and concentrated solar thermal power from abundant sunlight supplement solar photovoltaic power.

Rocket designs include advanced materials, such as Metal Organic Frameworks (MOF) embedded into the spacecraft's outer layer to store hydrogen for power and protection from cosmic radiation.

Highly nutritive-dense dried vegetable foods have been developed for stability over long time periods and changes in temperature and pressure, for crews on future deep space missions.

Digital health has extended to spacecraft and lunar habitats, with wearable sensors continuously monitoring astronaut health to detect minute changes, and programmable synthetic biology factories able to produce medicinal compounds to treat conditions as they arise.

3 Enabling growth

Recent developments in the space ecosystem, such as those highlighted in the trends (Section 1) together with the establishment of the Australian Space Agency, indicate that Australia's space industry has reached an inflection point and is poised for growth. This report touches on some of the areas of strength within the local research and business community where Australia can make a significant contribution to the global space industry.

In order to grow the national space industry, Australia must take advantage of its natural advantages and strengths that align to industry trends. To fully exploit these advantages requires investment in key foundational enablers, including infrastructure, business ecosystems and R&D capabilities. Examples of these are provided in Table 4.

Importantly, the success of Australia's space industry will depend on its ability to inspire and to demonstrate the connection between the space economy, its impact on the lives of Australians and the competitiveness of the nation's industries. Growth of Australian space ventures will see more opportunities to both spin in leading Australian technologies and capabilities, and to spin out space-derived technologies into everyday life.

Attendees at the CSIRO Space 2.0 Workshop, June 2018

TABLE 4: ENABLERS FOR THE GROWTH OF AUSTRALIA'S SPACE INDUSTRY

	SPACE-DERIVED SERVICES
INFRASTRUCTURE AND CAPABILITIES	• **High-performance computing (HPC), secure data storage and platforms** – growing demand for space-derived data is driving the need for massive secure data storage solutions and improvements in availability, resolution and functionality of government data platforms to enable commercialisation of space-derived data services. HPC infrastructure and associated expertise is critical to curating, processing and analysing raw data streams for translation into meaningful information products that provide insight for research, industry development, and decision making. • **Ground station infrastructure** – strategic regionally distributed and interconnected ground station networks are needed for advanced real-time communications and data access from multiple space-based systems. • **Access and tasking of satellites** – in 2017, CSIRO purchased a 10% share of time on the new UK NovaSAR satellite. Despite this, Australia still heavily relies on foreign-owned satellites for EOS data, which presents continuity of supply risks. Continual engagement and investigation of opportunities to co-invest in and share access to satellite data is essential to ensure diversity of supply and ongoing access to critical sources of EOS. Australia may also consider designing and launching its own Earth Observation satellite(s) to lock in sovereign access to data and enable Australia to command and control its own data stream. • **Calibration and Validation facilities and capabilities** – continued development of Australian calibration and validation (cal-val) facilities, capabilities and reputation is needed to ensure both the future growth of the EOS industry and Australia's continued contribution to international EOS missions. • **Launch facilities** – without access to convenient commercial launch facilities, Australia's space industry needs to look offshore for launch capability. With only 12 countries housing orbital launch sites,[25] Australia's southern hemisphere geography, wide range of usable site latitudes and low population density make it well suited for launch facilities that are capable of attaining most orbit inclinations. Further analysis is needed to assess the demand for cost-effective sovereign/commercial space launch capability and international regulatory obligations.

25 Bryce Space and Technology, LLC (n.d.). *Global Space Industry Dynamics*, Department of Industry, Innovation and Science, Canberra.

SPACE OBJECT TRACKING

- **Ground station infrastructure** – improvements to the quantity and performance of Australia's ground infrastructure are needed for better tracking of space objects. This includes more regionally distributed and networked ground stations, high speed data connections and improved real-time communication.
- **High-performance computing** – access to secure HPC facilities and capabilities is a key enabler for Australian space activities. This will support all phases of activity from formulation of hypotheses to conceptual design, analysis, and mission operations. Ongoing support and investment is critical to ensure continued HPC capability growth to meet the computational demands of Australia's future space industry, with increasingly complex simulations.
- **Communications infrastructure** – Space Situational Awareness infrastructure, such as ground station networks, will be enabled by regional development of vital communications infrastructure.

SPACE EXPLORATION AND UTILISATION

- **Local innovation hubs** – strategically located innovation hubs across Australia, where companies can go to develop, test and evaluate their ideas and technologies, will help drive innovative space exploration sub-systems.
- **Pilot-scale minerals processing** – Australia's minerals processing industry is world-leading. By leveraging this capability, the nation could develop facilities to assist with the development and testing of minerals processing procedures for extreme environments (e.g. microgravity).
- **Advanced manufacturing facilities** – a thriving new space industry based on miniaturised spacecraft, sub-systems and novel launch technologies requires flexible, comprehensive and cutting-edge manufacturing facilities for development, testing and scale-up.
- **Collaborative observing systems for space resource mapping** – space resource utilisation is a major technological challenge in its very earliest stages. Space resource extraction, particularly for fuel, will be a critical enabler for sustained activity in space but investments in this field today are exposed to extreme risk. A rational first step is mapping, assessment and exploration of available resources. This can begin with greater industry access to data from ground observing systems integrated with emerging in-space platforms, including the latest radar, radio and optical systems along with data analysis techniques.
- **Testing facilities** – Australia has many environments and capabilities that can be leveraged for unique testing facilities, including for unknown samples from space. Returned irradiated components and unknown samples from asteroids, the Moon and Mars must be tested and established to be safe in a high containment facility (like the Australian Animal Health Laboratory). Australia's outback and remote environments can be used for unique testing facilities, including as Martian analogues, and Australia's HPC capabilities can be used for space technology development and testing, through computer aided modelling for engine and spacecraft design, fluid dynamics modelling and simulation of flight.

CONT. TABLE 4: ENABLERS FOR THE GROWTH OF AUSTRALIA'S SPACE INDUSTRY

	SPACE-DERIVED SERVICES
BUSINESS ECOSYSTEM	• **Collaboration and industry development** – partnerships are essential to growing the space-derived services ecosystem. Nationally and internationally, companies and Space Agencies will need to collaborate to support industry growth and develop focused applications for space-derived insights that are actionable and applicable. Dedicated industry development, including efforts towards clustering, networking, funding, and international delegations, will be important. • **Business models** – innovative business models focused on distributed ownership / sharing of assets, co-location of research and business, identification of new customers, and new platforms that add value to space-derived data by providing decision-ready information will help grow the industry, develop new markets and deliver new services. • **Government data and purchasing** – continued open Government repositories for data are critical for development of value-adding space-derived services. Alongside commercial market development, judicious Government procurement of locally developed space innovations will encourage and help build Australia's space industry, and help to maintain a critical mass of capabilities in the country. • **Education and training** – ensuring industry has access to an appropriately skilled workforce is vital to this opportunity, both within the upstream space industry but also in downstream industries. Inspiring future STEM professionals through the secondary education system, together with more focus on practical applications and deeper industry engagement throughout tertiary education, will help grow the future workforce.
RESEARCH AND DEVELOPMENT	• **Satellite and sensor development** – including small footprint power systems and energy storage, low-power on-board computing, advanced communications, improved accuracy, novel lightweight materials and coatings, a broadened variety of sensors, etc. • **Novel data processing methodologies and platforms** – including artificial intelligence, multi-sensor fusion and on-board or compressive sensing and processing. • **Data and satellite security innovation** – including secure-by-design principles and privacy controls. • **Technologies for faster in-space and space-to-ground communications** – such as terahertz systems, downlink of multiple data streams from several small satellites simultaneously, and higher-bandwidth downlink, including laser downlink. • **Proof of concept for downstream applications and third party validation** for Australian technologies entering foreign markets. • **Continued innovation in launch technology** towards lower cost, reusable systems.

SPACE OBJECT TRACKING	SPACE EXPLORATION AND UTILISATION
• **Collaboration and partnerships** – public-private partnerships are essential to enabling commercial services for space object tracking, allowing commercial users to have access to assets. • **Business models** – innovative business models focused on distributed ownership / sharing and platforms will be needed to help grow the industry and deliver new services. • **Dual use systems** – new measures to support the dual use of infrastructure and technology between defence and commercial applications would be beneficial to commercial growth of the space ecosystem. • **Regulation of modern space activities** – clear space regulation and standards are important for providing investment certainty for space-related business activities and encouraging innovation and growth of the space industry. This includes clarification around ownership of space assets (and associated debris). • **Government as a customer** – judicious Government procurement of locally developed space innovations will encourage and help build Australian businesses and maintain a critical mass of capabilities.	• **Partnerships** – this opportunity involves integration into global value chains for foreign space agencies with space exploration goals. Australia needs to establish partnerships with NASA, ESA, JAXA and other international space programs to allow the transfer of technologies for exploration missions. • **Legal expertise** – specialist legal expertise in managing intellectual property will be needed to streamline exploitation of Australian-developed technologies on exploration missions. Further, expertise is needed to ensure compliance with various regulations, such as International Traffic in Arms Regulations (ITAR) in the USA, helping to streamline the development and commercialisation of Australian technologies. Australia also needs to be part of the global conversation regarding living and working in space and the ownership of space resources and assets. • **Technology diffusion and knowledge transfer** – a key driver for space exploration R&D is the applicability of these technologies to land-based industries and daily life. To fully exploit the value of space technology, the industry must be connected with all established Australian industry sectors. A dedicated forum focused on translation of these technologies into other industries could help fast-track international collaborations and technology and knowledge transfer both into and out of space programs. For example, the impetus for deep space missions to make equipment smaller, lighter and more robust is particularly useful for the mining industry. • **Education and training** – broad skills are required for the development of exploration and utilisation technologies across diverse areas, including but not limited to science, technology, engineering and mathematics. Inspiring the next generation of science and technology professionals is imperative to growing this opportunity.
• **Continued improvements to optical and radar sensors** – including sensitivity, range and power requirements. • **Novel data processing methodologies and platforms** – including artificial intelligence, on-board processing and other high fidelity, advanced simulations for orbital tracking together with advanced real-time risk assessments. • **Solutions for autonomous active debris removal and mitigation of new space debris production** – such as passive de-orbiting solutions, active interception, novel actuation, autonomy and decision support tools. • **Advanced communication systems for space** – including terahertz and microwave communications.	• **Continued innovation in power and propulsion** – technologies towards lower cost, reusable and sustainable systems. • **Innovation in advanced manufacturing systems** – including in-situ space-based manufacturing and processes for manufacture of novel products. • **Remote healthcare solutions** – including technologies for monitoring and treating humans in space. • **Solutions for food –** including production systems in space and novel stabilised foods. • **Continued innovation in habitation technologies** – high safety and reliability. • **Advances to knowledge and processes for in-situ resource utilisation** – including mapping available resources and re-engineering mineral processing technologies for lunar or space conditions, and developing systems to utilise the resources, such as additive manufacturing technologies. • **Continued development of autonomous systems for robotic exploration missions** – including improved fidelity and functionality, and persistent and competent autonomy.

CONTACT US
t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au

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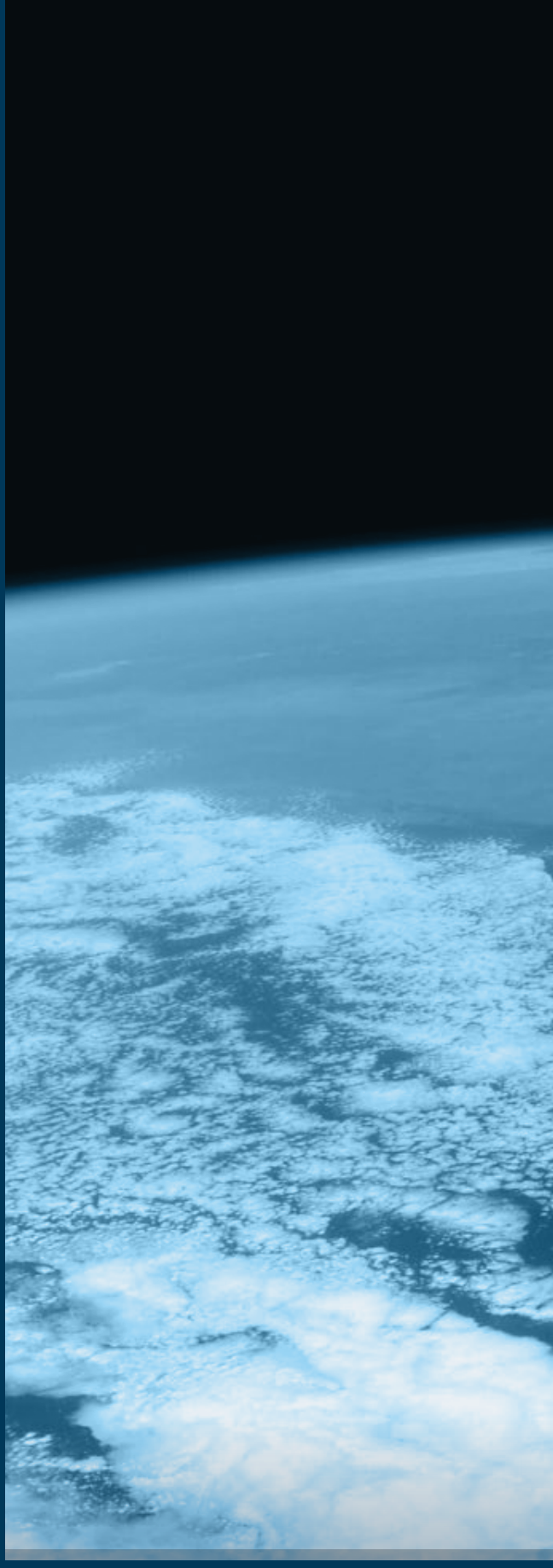
FOR FURTHER INFORMATION
Dr David Williams
Executive Director, CSIRO Digital, National Facilities and Collections
t +61 2 9490 5621
w www.csiro.au/Space

James Deverell
Director, CSIRO Futures
t +61 2 9490 8456
e futures@csiro.au
w www.csiro.au/futures



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