Professor Mark Scott AO
Vice-Chancellor and President

12 May 2023

Professor Bronwyn Fox
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Dear Professor Fox,

National Robotics Strategy: discussion paper

Thank you for the opportunity to participate in the development of the National Robotics Strategy. We welcome the opportunity to make a submission and trust that Advisory Committee members will find our input useful.

The University of Sydney has an outstanding record of contributing to robotics innovation and a highly skilled workforce in Australia, our region and beyond. Established more than 25 years ago, our Australian Centre for Robotics (ACFR) has grown into one of the largest robotics research institutes in the world, having made numerous research breakthroughs, often in partnership with the private sector or with government. (In fact, the Centre's inaugural leader is a member of the Minister's Advisory Committee, Professor Hugh Durrant-Whyte, NSW Chief Scientist and Engineer.)

It is without contention that the ACFR has played the most crucial role in the development of the nation's robotics sector, cementing our global reputation, both in industry and academia. Innovations from fundamental research at the ACFR over the past two decades are significant drivers of automation in the resources sector, transportation (including autonomous vehicles), agriculture and forestry, security and defence, and marine systems.

A leading example of this is the ACFR's highly successful and ongoing partnership with Rio Tinto through the Rio Tinto Centre for Mine Automation (RTCMA), established in 2007. This continues to be the single largest investment by a private corporation in university research in Australian history. The RTCMA has pioneered the transformation of the resources sector from one with no automation prior to 2007 to where it is today – a leading adopter and innovator in industrial field robotics. This is an important case study for the Department as this partnership has evolved over the years from autonomous drills and trucks to today having a large emphasis on whole-of-mine optimisation and intelligent decision making. These principles are applied to energy efficiency, design and decarbonisation to support Rio Tinto's Net Zero ambitions.

Another important example is the ACFR's development of the *Constellation* flight planning system for Qantas. This is by all measures the most sophisticated flight planning system in the world. It has enabled Qantas to save more than $40m per annum on fuel expenditure and reduce their carbon footprint, in addition to equipping them to deliver the longest commercial flights in the world, reducing cost and transit times for their customers. This is a serious competitive advantage for an Australian company operating in a highly competitive, low-margin, global industry. It was also the result of a scientific breakthrough in fundamental research funded by government.

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Intelligent systems like these are where Australia can lead.

The ACFR has also contributed significant influence on global robotics research, as can be seen through our alumni now leading other internationally renowned robotics research groups like Oxbotica in Oxford (UK), The Robotics Institute at Carnegie Mellon University in Pittsburgh (USA), and here at home at the UTS Robotics Institute. ACFR research has enabled numerous successful Australian startups like Abyss Solutions (pioneering autonomous inspection across land, sea, air and space), Green Atlas (for precision crop yield management), Baymatob (developing AI solutions to improve health outcomes for mothers and babies), Mission Systems (for defence autonomy and intelligent systems), and many others.

It is important to understand that these examples of major industry impact were built directly on investment in fundamental research on the deep scientific challenges of robotics in the decades prior. With Australia's investment in basic R&D declining while other countries dramatically increase their stake, Australia risks foregoing such opportunities in the decades to come. Furthermore, it cannot be understated that Australia's current competitive advantage in both academia and industry is at the very forefront of technological development in advanced robotics and intelligent systems. This cannot be sustained without a strong, world-leading higher education sector – to ensure we can continue to make major breakthroughs and train these highly skilled workers that will support the industry.

With an appropriate level of ambition and support from the Commonwealth – working in partnership with the states, territories, education providers and industry – Australia is well placed to establish itself as the destination of choice for the world's robotics talent, investment, research and innovation. A meaningful National Strategy could see robotics extended to all industries that are significant for our sovereign economic and strategic security, making them stronger, more productive, sustainable and internationally competitive.

Experts from our ACFR team would be delighted to discuss their **attached** submission with members of the National Robotics Strategy Advisory Committee, or to provide more information on any issues arising and current projects relevant to the development of this important strategy. The University and ACFR would also welcome you, members of the Committee and departmental officers for site visits at any time – please note that these visits can be organised at short notice.

Should you or members of the Advisory Committee wish to hear further from our robotics experts, please do not hesitate to contact Professor Ian Manchester, Director, Australian Centre for Robotics at ian.manchester@sydney.edu.au or (02) 9351 2186.

Yours sincerely,

(*signature removed*)

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Vice-Chancellor and President

Attachment Australian Centre for Robotics, The University of Sydney, submission to the Department of Industry, Science and Resources' National Robotics Strategy Discussion Paper, released April 2023

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Australian Centre for Robotics feedback to the Australian Government's '*National Robotics Strategy Discussion Paper*', May 2023

Definition

1. Do you agree with the definitions in the discussion paper? If not, what definitions do you prefer?

The intent of this strategy is to leverage Australia's world-leading robotics research and innovation expertise into a coordinated national initiative to further enhance domestic development, production, adoption and export of world-leading robotics technology.

We believe the above statement is the context or lens through which robotic definitions should be viewed. While we agree notionally with these definitions, they are traditional in the sense that they could be applied universally where robotics are of interest on any level. Rather than a request to change the stated definitions, the following is perhaps more a comment or suggestion as to how to think about robotics from the perspective of Australia's unique capabilities.

With this in mind, we do not believe these definitions fully capture what is uniquely special about the Australian robotics sector or the unique challenges and contributions that have been made to robotics in Australia. There is a considerable chasm between the autonomy of robot arms on an assembly line and the autonomy of systems we see operating in Pilbara mines.

Australia's reputation is not in developing traditional robotics or "basic" autonomous systems - rather our reputation is built on the development of highly sophisticated intelligent systems, usually for application in high-value industrial settings which are not always physical.

Intelligent systems are capable of evaluating complex and dynamic environments and situations to determine the optimal action or series of actions required to achieve a goal or outcome. They can be physical and/or non-physical. Insight generation can be autonomous but may not result in action or interventions from physical robots. This is fundamental to field robotics but is not captured in the definitions.

Optimisation is another form of robotics applied in both discrete robotic systems to manage competing interests (e.g. power and acceleration) and large-scale processes and operations (e.g. mine sites or large industrial agriculture), where numerous interdependent processes need to be undertaken simultaneously at any given moment. The latter is noteworthy as it is an area of considerable strength in Australia and if broadly applied across Australian industry could have transformative outcomes for the economy. It is also not strictly physical robotics, even if outcomes may be executed through physical robotics. Similarly, it is also not strictly automation, even though the inputs and outputs could be autonomous systems. It is, however, robotic, and based on the definitions included, this would be excluded from the strategy which would be a great oversight.

Sensing, perception, mapping and insights is another area we would consider "robotics" despite it not having the mechatronic or autonomous qualities outlined in the definitions. Robotic perception of an environment that can be spatiotemporally mapped and provide insights about this environment is an area of significant value and rapid innovation. For example, consider a system that can be mounted on the roof of a car to detect and map defects in roads or tunnel walls autonomously as the driver drives the vehicle. In this instance, the absence of physical autonomy is irrelevant, as the value is through the autonomous generation of insights through the non-physical perception and mapping systems. This too would be excluded from the national strategy based on the definitions provided.

We would also argue that the definition provided above of robotics having four essential characteristics with intelligence being one of these characteristics excludes the majority of robotic systems installed in factories and assembly lines around the world. While these robotic systems can be programmed to complete complex tasks, they cannot really be considered intelligent in any sense of the word. The majority of these systems will follow scripted instructions and might respond to sensor input but they are not capable of reasoning and are generally unable to respond to ambiguous or novel situations.

These are just a few examples, however, the general theme that is relevant to this paper is the concept of elevated intelligence across all aspects of robotic technology and that robotics are not confined to physical systems performing physical tasks. Limiting the strategy to these definitions would exclude a considerable portion of Australian expertise and innovation.

Australia’s robotics opportunity

2. What is your vision for the future of robotics and automation in Australia? Are there any sectors or types of robotics that hold particular opportunities for our nation?

For decades, Australians have been told that we cannot have certain industries due to a compounding of factors including our vast landscape, sparse population, high wages and distance from global markets - all of which put upward pressure on production costs making us less competitive than our international peers. These pressures are real as we have seen them transpire through the incremental loss in industries like automotive manufacturing and steel production, and the inability of many of our regional communities to create vibrant and self-sustaining economies.

While these pressures may be real, significant technical innovations over the past decade mean they can now be largely overcome. It is for these reasons that we see robotics, automation and intelligent systems as a crucial, nation building technology. Our vision for robotics in Australia is therefore one where we decide what industries and capabilities we want here and invest in the development of robotic systems to ensure they are economically viable.

Australia’s well-known credentials in this space provide a glimpse as to where we can establish ourselves as global leaders developing and exporting robotics technology. It seems unlikely that we will be successful developing and exporting robotics technology that is already largely adopted in industry, or that wholesale adoption of this ubiquitous technology will be sufficiently transformative. **Where we have demonstrated a consistent competitive edge is through the development of sophisticated intelligent systems, higher-level autonomy and bespoke solutions in high-value industries**.

An excellent illustration of this is the flight planning system *Constellation* the Australian Centre for Robotics developed for Qantas. The system fuses numerous data sources affecting flight efficiency to determine the most fuel and time efficient path to its destination. It enables Qantas to save over

$40 million a year on fuel, reduce their carbon footprint, and provide the longest direct international flights of any airline, drastically reducing transit times for customers. This is a considerable competitive advantage for a company operating in an industry with notoriously low margins, and often dependant on government support to sustain itself.

We can apply this reasoning to industries all around Australia, encouraging them to think about and invest in optimising all aspects of their operation, removing inefficiencies, making them more globally competitive - in manufacturing, resources, agriculture, automotive, logistics or defence to name a few.

We are surrounded by numerous examples. Australia is entering one of the most intensive shipbuilding investments in the nation's history through the Navy Frigates programs and AUKUS. Shipbuilding is notoriously inefficient due to the scale of construction with estimates indicating just three hours of an 8-hour workday are spent on actual construction. This is an industry-wide issue and therefore presents an opportunity for Australia to not only support Australian naval ship building but create a globally competitive ship building industry capable of servicing all sectors.

These principles also dovetail perfectly with the unique needs of Australian agriculture. Australia's vast landscape and significant distance between regional hubs mean the agricultural potential of many of these remote communities is unrealised as the cost of production, shipping of goods in and produce out is uneconomical. A prime example is the Ord River Development Scheme in Northern WA, with 70,000 hectares of potentially prime arable land with a sustainable, annually replenishing water supply, in a remote and sparsely populated part of Australia. Despite billions of dollars of investment to transform this region into an agricultural hub, these efforts have largely failed. Higher-value crops require more broad based low-skilled labour which the region cannot supply; transport of necessary goods and produce over such long distances is incredibly costly; traditional farming practices like crop dusting are grossly inefficient, and the cost of these inefficiencies is magnified by the distance and costs to transport goods. Consequently, higher-value crops have consistently failed despite the land being highly productive. This is a quintessential encapsulation of all the reasons why Australia should embrace robotics as a nation-building technology. Holistic agricultural robotic systems would remove the multitude of inefficiencies preventing a viable agricultural industry in the Ord, completely transforming the economics of a region.

Opportunities can be extended even further using this example. The cost of production is high, largely because it is expensive transporting goods such long distances and because trucks can only be driven for 12 out of 24 hours. Consider if freight vehicles could operate 24/7? The current orthodoxy on autonomous vehicles (AVs) is that their introduction into mixed-use civilian environments will occur in stages or zones; the first being low-complexity infrastructure like highways. Northern WA is possibly the most ideal place in the world to establish the first of these zones, with long, straight, high-quality roads that are sparsely populated with low traffic. Embracing the mission to research and develop fully autonomous freight networks in Northern WA would halve the time it takes to transport goods and put downward pressure on production costs, completely transforming the economics of this entire region. Cheaper, faster freight would enable new industries and jobs creation that would have otherwise been uneconomical. It would establish an internationally lucrative AV industry to the region as startups and investors flock to the area in a race to develop and test the best AV technology to be exported to the rest of the world. This is not some lofty 'thought bubble' - this region already has one of the highest densities of AV deployment in the world servicing the iron ore industry. One of the ACFR's major research partners, Rio Tinto, is now working with Scania to develop more "normal" sized autonomous trucks suitable for highways because autonomy now makes it more economical to mine using vehicles with standard dimension, with standard parts, that are easier mechanics to maintain instead of highly-paid diesel engineers. It will also make the task of electrifying the mining industry much easier. Imagine the industries that could thrive around this, the expertise that could be developed at all tiers, the investment and economic opportunities for Australians. This is precisely what we mean when we say robotics should be embraced as a nation building technology for Australia.

Defence is another area Australia has the capacity to establish itself as an international leader and supplier of technology to our allies. Australia's reputation is incredibly strong in the domain of field robotic systems and remote operations, and defence technology is largely moving in this direction. Multiplatform coordination, intelligent decision making, operation in communication denied environments, removing humans from dangerous environments, are all important to Australia's defence forces (ADF). In 2022, the RAAF released a list of pressing issues on which they were requesting EOIs to develop bespoke solutions. Eighty per cent of these were robotics problems. A coordinated triple helix of industry, academia and defence would put Australia on a path to becoming a major developer of world-leading defence technologies which is what occurs in the US. The U.S. Department of Defense understands the value of robotics and intelligent systems which is why they have a long-term partnership with the nation's leading robotics research capabilities at MIT through the Lincoln Laboratory. This is a well-respected and high-profile facility that defence can easily access for advice and to fund research on pressing issues. In this regard, we believe the ADF could be taking better advantage of Australia's leading robotics research expertise by establishing a similar facility here.

Robotic systems for clinical applications is a greenfield opportunity where Australia could take a leading position. This is an area that currently falls outside research funding structures. In short, clinical research funds (NHMRC) do not fund engineering research, while science research funds (ARC) do not fund clinical research. Consequently, intelligent systems we now consider standard in many industries do not exist in clinical applications. This is a great opportunity for Australia should we coordinate better collaboration between our outstanding healthcare system, world-leading research expertise in robotics, medicine and surgery, and industry.

The opportunities for robotics in Australia are tremendous and arguable greater than any other nation due to the unique economic pressures we experience that robotics are designed to mitigate. It is exciting thinking that Australia could be known internationally as the leading developer of intelligent robotic systems because we decided we wanted certain industries here and we embraced this technology to overcome the hurdles making them uncompetitive. Australia already has all the building blocks here to achieve this. World-leading research capabilities and facilities, major industries like resources and agriculture that are embracing this innovation, and well-managed publicly funded service delivery in health, education, defence and environmental management. A nationally coordinated and funded initiative would be profound and transformative.

3. How should we measure the growth and success of robotics in Australia? What methodologies would ensure robust and reproducible evidence?

There are a variety of metrics that would make it easy for the government to evaluate performance.

- **Government funding of robotics projects** – government departments in Industry, Education, Agriculture, Health, etc, all provide a variety of funding schemes accessed by industry and academia. Some of these could even provide historical data e.g. from the ARC and the CRC program. Drawing data from these would provide a good measure of robotics growth, adoption and innovation.

- **Industry commissioned research at universities** – this data is already collected at universities. It would be possible to monitor how much of this is invested in robotics research.
- **ESIC taxation category for hardware** – outlined in more detail below, however, a new category of Early-Stage Innovation Company for hardware would allow the government to monitor private investment in robotics. It would also lower the risk profile of robotics investment.
- **Startup creation** – self-explanatory. University spinouts are detailed in annual reports. Reform of university spinout policies is needed. It would be easy to monitor the performance of reforms through these reports.
- **Skilled migration – attracting the world's best talent is an important metric of success.** The importing of talent for research and industry.
- **Government procurement** – money spent adopting and acquiring Australian made robotic systems by government each year across all departments (excluding robotics made in Australia by foreign companies).
- **Productivity** – measuring productivity growth in industries accessing government grants to adopt or develop robotics.

National capability

5. What are Australia’s existing strengths in robotics and automation research, development and production? How can we build on these?

As previously stated, it is unlikely that Australia will be successful through the development and application of robotic technology that has been ubiquitous in industry for several decades now. Australia’s competitive advantage is in the development of highly sophisticated, intelligent, cooperative and optimised robotic systems. While the adoption of industry standard robotic technology is valuable, in this instance our point of differentiation will be how we use and optimise these systems to develop high-value sophisticated solutions for industry.

Robotic arms, for example, have been a mainstay in manufacturing for many decades. Where Australia can create a competitive edge is developing systems that allow them to undertake increasingly complex and high-value (or high-cost) tasks, within a highly optimised and automated process. A current project we have that encapsulates this is in manufacturing where, after each part is produced, very fine, hard to detect residue needs to be removed before a new cycle can be started. This takes several hours and is performed by highly-paid engineers, with the time it takes also affecting downstream processes on the part. An ‘off the shelf’ robotic arm solution does not exist to automate this process and therefore a sophisticated system will need to be developed drawing on expertise in sensing and perception, mapping and insights, planning, control, learning and optimisation.

This is where Australia has considerable strength and competitive advantage - complex dynamic systems, planning, control, modelling and optimisation, learning, and mechatronic systems are all areas Australia has world-leading research expertise that can be applied in a variety of industrial settings to develop novel solutions that do not currently exist anywhere. We are not advocating that Australia should not develop off the shelf robotics platforms or solutions; what we are saying is that our competitive edge will be through the development of the highest quality novel solutions.

A great example of this is Reach Robotics, an Australian startup focused on building robotic arms. The robotic arm industry is well-established with a variety of players with varying quality and price points. Reach Robotics are not looking to compete with these companies in traditional application domains like assembly lines - they are developing robotic arms for underwater robotic systems. Underwater environments, especially salt water, are harsh on robotics systems, however, high-value industries like oil and gas operate in these environments and they have great need for robotic systems. Reach Robotics is therefore carving out a high-value niche within the robotic arm industry developing the highest quality systems for these applications.

Developing new markets for robotics is another particular strength in Australia. It is difficult to imagine mining today without automation, however, this was precisely the landscape just 15 years ago. This industry transformation was an entirely Australian innovation that today extends well beyond the autonomy of individual drills and trucks and is moving more and more to "whole of mine" optimisation that incorporates all aspects affecting production from ore body extraction, to scheduling, processing and even energy inputs and efficiency. Much of this is made possible through automation and robotics. High-frequency, optimised adjustments can be made to operational plans, however, for such changes to be respected and enacted operationally requires the kind of attention and conformance that only an automated system can provide. An autonomous vehicle can receive dispatch instructions or changes to operational parameters several times per second, and respond accordingly, while human-driven trucks will have much lower conformance to such demands.

There are so many sectors Australian roboticists in both industry and academia could transfer these learnings with the appropriate coordination and support at a federal level. Agriculture is an immediately obvious one due to its parallels with the resource sector, with large areas of potentially arable land in very remote locations with insufficient population to service a potential industry. Whole-of-farm robotic operations would enable these communities to unlock these economic opportunities while simultaneously providing higher skilled and paid job opportunities for locals. The major difference with the resources sector is that agriculture is not dominated by monolithic entities like the resources sector is; it is primarily made up of cooperatives of smaller scale farmers and operators. The government therefore has a role to play coordinating this industry transformation in Australia if it sees it as a priority.

We have countless examples of these in defence, medicine, construction, manufacturing, environmental management, energy, transport, logistics, shipping, etc, where Australia could realistically emerge a global leader. We could speak at length about these, but for the purposes of this paper it is important to discuss the 'how'. There is a suite of options a National Strategy could consider.

1. *Fundamental Research*

The theme of our submission is that Australia's opportunity in the global robotics ecosystem will be through the development of the highest quality, most sophisticated and intelligent robotic systems. While this is already our reputation, this reputation is a result of, and can only be sustained and grown by, ongoing and reliable support for fundamental research. Fundamental research - whether government or industry funded - is by its very nature the absolute forefront of technological development. To add some context here, Australian innovation in field robotics over the past two decades has enabled us to stand out internationally as a trailblazer through the development of robotic systems in the resources sector, agriculture, marine, autonomous vehicles, to name just a few. This explosion in innovation would not have been possible without the scientific breakthrough of Simultaneous Localisation and Mapping (SLAM), a technology that allows a robot to build a digital image of its surrounding environment in real time and orient itself within that digital reconstruction. This profound breakthrough was achieved at the Australian Centre for Robotics (ACFR) at the University of Sydney and was the result of fundamental research. In advanced technologies, fundamental research is integral to sustained innovation. If Australia is to maintain and build its reputation as a leader in robotics technology, a strong fundamental research ecosystem must be at its core.

Unfortunately, Australia is falling embarrassingly behind on research investment compared with other developed nations. Normalising for the COVID pandemic, Australia's research investment as a percentage of GDP is 30 per cent below the OECD average of 2.56 per cent and trending downwards at 1.78 per cent. This looks even worse when measured against nations like the US who invest 3.45 per cent of GDP on research, almost double. Countries like Israel who also have the highest per capita venture capital investment in the world invest 5.22 per cent of their GDP on research, and South Korea 4.63 per cent These are countries renowned for innovation, translation and investment. Perhaps most concerning as we move into an increasingly technological age, we see countries increasing research investment as a percentage of GDP each year. Australia is one of the few countries where investment is trending downwards.

Looking at this through the scope of robotics, at the ACFR we are 90 per cent industry funded which is something that we are very proud of. However, this also masks considerable drop off in government funded blue sky research. ARC Discovery Project grants have become increasingly difficult to secure and provided declining funding in real terms. It is this kind of funding for blue sky research that enabled the SLAM breakthrough. Furthermore, increasingly unreliable funding is resulting in greater job insecurity for researchers. When we lose talented researchers to the private sector because we are unable to secure funding for their continued employment, they typically do not return, and Australia loses the considerable investment in their development. If Australia is to maintain its position as a global leader in robotics research these things must be resolved.

2. Applied Research, Translation and Commercialisation

Robotics research by nature is applied research. Robotic systems are developed and built to perform existing tasks and purposes. For this reason, innovations in fundamental research have a much shorter pathway into applied systems when compared with disciplines like health and medicine (the previous example of SLAM applies here also).

However, as will be said throughout this submission, hardware development is difficult, and it is expensive. Research translation and industry research support schemes provide an invaluable link by enabling the integration and testing of fundamental innovations in real world systems, whether they be industry systems or platforms developed in universities.

Expansion of these industry translation programs such as the ARC Linkage Projects and CRC-Ps grants would have a significant impact. The CRC-P program that is overseen by the Department of Industry, Science and Resources is particularly effective for this kind of coordination of fundamental, applied and translational research, however, the pool of funds is small, and is one of, if not the, most oversubscribed funding schemes in the country with a lower success rate than the ARC and NHMRC. The CRC-P program is specifically designed to develop novel solutions for industry, so an increase in this fund that is preserved for robotics projects would drive significant innovation and creation of first-in world robotic systems. The same principles could be applied to industry innovation support programs like the Research and Development Corporations, Industry Growth Centres and Cooperative Research Centres.

Making it easier for researchers and technical staff in universities to use their robotics platforms in commercial work would also deliver great outcomes. Generally, university staff are not permitted to do this as it is seen as a conflict of interest and are therefore made to choose one or the other. A more flexible and transparent arrangement for university staff to experiment with the commercial potential of their innovations would not only drive investment in new robotics startups, it has the potential to provide a valuable funding stream for research groups to continue to improve their technology. Australian universities have a preference to take a considerable equity stake in researcher's startups, often well over 30 per cent, and while it can be argued that this is completely justifiable, it is not the model used in world-leading startup ecosystems around Stanford and MIT. The ACFR has been responsible for a considerable number of startups and the feedback is always that the Australian model disincentives them. We do not think this is healthy for the fledgling robotics startup ecosystem in Australia that already has a significantly higher risk profile than other technology groups.

3. *Procurement policy and industry support schemes*

Mentioned throughout this submission is the important role the Australian Government can play in supporting the development of a robust robotics industry in Australia. Many areas the Department has identified as priority areas for robotic systems are areas where the government is the major stakeholder. Defence, health, space and environmental management are all the domains of government, and minor tweaks to things like procurement in these departments could have a tremendous impact. Ensuring that all relevant departments have robotics and automation strategies as part of their efficiency and service delivery performance evaluation would force these departments to identify inefficiencies, cost sinks, and ways to improve service quality areas for robotic innovations. Having a "buy Australia" procurement policy that also enables suppliers to propose solutions that could be developed would drive adoption and invention of Australian-made robotics. Government contracts are highly valuable insofar as they are often consistent and reliable sources of funding, therefore, this would decrease the risk profile of robotic inventions and development (discussed below), a huge barrier to robotics startups becoming self-sustainable.

There are already a variety of high-value industry support programs underway in Australia in areas where robotics could deliver great value, including the new National Reconstruction Fund, Australian Renewable Energy Agency (ARENA), Industry Growth Centres and Research and Development Corporations. Ensuring that industry develops a robotics strategy as a criterion for them accessing government support would ensure that these industries are thinking more proactively about ways in which they can automate their operations and become more productive.

Both these examples would enable the development of a home-grown capability. Australian industries that are able to access and supply government services and customers would provide the consistency this industry needs to become sustainable which would ultimately make Australian robotics supply chains more robust.

6. In what related areas could Australia develop world-leading expertise?

1. *Planning & Control*

Planning and control are the components that endow robots with "intelligent behaviour". In essence, planning and control answer the question of what the robot should do *now*, when each decision has long-term consequences. This question encompasses multiple levels, from mission planning that decides the high-level missions that the robot must undertake, to motion planning that decides efficient motion strategies for achieving the mission, to control that decides optimal sequence of control inputs to accomplish the motion. For example, in the context of a mobile robot inspecting an asset such as an offshore wind farm, inspection from a distance becomes difficult, if not infeasible, due to obstructions and complex asset geometry. On the other hand, robotic inspection conducted at close proximity to the asset significantly increases the risk of collision, especially when the asset is located in a challenging environment (e.g., high winds, water currents). To alleviate these issues, all levels of planning and control must be able to account for uncertainty as well as for the robot's kinematic and dynamic capabilities. This requires mission planning, motion planning, and control to be robustly entwined. Methods that directly account for uncertainty and robustly entwine mission and motion planning have been proposed, and when feasible have been known to substantially improve performance. However, computational scalability of these methods remains a significant challenge, and guaranteeing safety in inspection and maintenance of large and geometrically complex structures remains an open problem. This is an area of obvious future industry importance in which Australia is doing leading fundamental research, and thus represents an opportunity for future impact.

2. *Sensing & Perception*

Australia stands uniquely poised to lead in the development of sensing and perception tools to enable sophisticated, reliable and trustworthy autonomy. This involves advancing both unique sensing hardware and machine learning approaches to interpret them into actionable models. Bespoke sensing promises to improve robotic autonomy in challenging environments, where factors like challenging weather, murky water and low light confuse current approaches. Recent developments in optics, machine learning, and computational imaging point the way forward, offering better performance and new senses like single-photon detection, imaging around corners, and the ability to follow a moving pulse of light through a scene. However, most of these developments have so far arisen outside robotics, leaving unaddressed the unique characteristics of robotic perception: robots are embedded in their environments, experience a continuum of states, and can generally move and interact with objects to perceive better. These unique characteristics open up opportunities for sensors to query the environment dynamically and to use manipulation as part of the perception process. Timing is also critical: where conventional vision algorithms are concerned chiefly with throughput, or are not concerned with runtime at all, latency is a key factor in robotic applications where safe operation requires timely decisions. This issue is exacerbated by limited platform power and mass, restricting available computational power. The opportunity to become a world leader in addressing these challenges builds on Australia's existing and growing strengths in sensing and complementary robotics capabilities in autonomy including planning, mapping, and control. It also benefits from the advanced manufacturing, integrated optics, and nanotechnology capabilities growing in Australia, as these are key enabling technologies in the development of novel sensing systems.

3. *Mapping & Insights*

Creating high-quality 3D virtual models of complex physical objects and environments involves repeatedly sensing the environment and fusing sensor measures into a consistent representation. Robotics simultaneous localization and mapping (SLAM) is a well-researched area in robotics, with the earliest solutions emerging from the research carried out at the Australian Centre for Robotics (ACFR). State of the art techniques incorporate artificial intelligence methods, such as deep learning within SLAM frameworks, and provide not only a geometric representation of the scene but also semantic and insights about objects and places.

The development of robotic mapping and insights technologies in Australia holds immense importance for environmental conservation, disaster management, infrastructure planning, resource exploration, agricultural productivity, and research advancements. Embracing and investing in these technologies can lead to more sustainable, efficient, and informed decision-making across various sectors, contributing to the overall progress and wellbeing of the country. Australia is a major agricultural producer, and the adoption of robotic mapping and insights technologies can revolutionise the farming sector. By employing drones and autonomous vehicles equipped with sensors, farmers can gather data on soil quality, crop health and water availability. This information can optimise farming practices, improve resource utilisation, and enhance overall productivity while reducing environmental impact. Similarly, in mining and resource management, autonomous robots can collect geological data, create detailed maps of mining sites, and assist in the planning and optimisation of resource extraction operations. Robots equipped with LiDAR (Light Detection and Ranging) sensors can generate precise 3D maps of cities, enabling better urban design, traffic management and infrastructure maintenance. Robotic mapping technologies can also provide valuable data on the state of these environments, enabling researchers and conservationists to monitor and protect them more effectively.

7. How can Australia improve its investment environment and access to capital to support Australian robotics companies?

There is an essential consideration that must be taken into account when thinking about how best to improve the investment conditions for robotics companies and startups in Australia, which is the common phrase “hardware is hard”. The risk profile of robotics is significantly higher than that of SaaS (Software as a Service) startups which is predominantly where Australian VC investment is flowing. Robotics by default has higher overhead costs: to build something physical you need a physical location to work; you also need to procure or make a variety of different physical, specialised parts requiring tools and expenditure - this is exacerbated by having to iterate parts to improve the design or get something to work; you also need a more diverse team of skills (mechatronic, electrical, software and industrial designers) and to coordinate iteration at all those levels into a single system. SaaS startups do not have these upfront costs in the way robotics startups do, and in many ways have an even lower threshold as a completely non-technical founder can now design a fully functioning codeless prototype of their platform to demonstrate and secure investment. A roboticist cannot do this. Time to market is also much longer for robotics.

Simply put, there is a risk profile imbalance for investors interested in robotics and if we wish to see more robotics startups in Australia, we need to improve their risk profile for investors. In 2016, the government made positive reforms of the tax system to stimulate the startup ecosystem in Australia by establishing the Early Stage Innovation Company (ESIC) classification. One aspect of this is the “non-refundable carry forward tax offset” allowing investors to use 20 per cent of an investment value to offset their tax each year. This is capped at $200,000. A separate or subcategory for early stage hardware companies could be created with an increased offset of 50 per cent and a cap of $1,000,000.

Another program that we see performing well is the Queensland Government’s Business Development Fund which co invests with VCs up to $5 million with a single startup and the VC has up to five years to buy the fund out of their options at cost plus interest. An expanded national version of this fund dedicated to robotics would be highly appealing to investors effectively enabling them to double their investment value with half the liability and increase their stake in the company at a cheaper valuation post validation.

R&D tax credits are also highly contentious in Australia as accessing them seems to be more about accounting knowledge than actual research investment. Startups we speak with say they do not have the in-house resources to make these applications easily and must contract consultancies at great cost. Reform of this system should be looked into, however, we think there are some fairly easy changes that could have an immediate impact. Companies that collaborate with universities on research projects have a variety of contracts, project schedules and invoices to prove their investment was in research. It seems unreasonable they need to submit an application making them justify to a reviewer that this was actually research. Investment with universities on research should be immediately categorised as an R&D tax credit as part of their normal tax return.

The CRC-P program is another great program for industry and investors in Australia. It is designed to bring together industry and academia to support the development of a novel technology for a high-value and unmet need. This is a perfectly designed grant that could support the type of robotic systems Australia is great at developing - high-end, high-value bespoke robotic solutions. A version of this grant dedicated to robotics would stimulate industry to consider new and creative ways they could use robotics, driving invention of first-to-world robotic systems.

It is also worth mentioning that VCs are not all the same. Different VCs invest in different technologies at different stages and by different amounts, informed by their experience, knowledge, strategy and profile. They are also not just people with money - VCs provide support and advice to founders which often draws on their experience commercialising the technology. Robotics is a niche investment class making VC/founder alignment invaluable. It is important that researchers who are interested in commercialising their IP have the autonomy to decide who they want to invest in their technology. In Australia there are structural and cultural factors that result in the university having a greater say on the terms of their commercialisation. As a general comment we see the onerous and protracted processes universities impose disincentivise researchers eager to experiment with entrepreneurship, often killing the idea before it had a chance to grow. Universities that are well known for their successful startup ecosystems have a lighter touch and supportive approach. This topic may require a discussion paper of its own, however, we do think this is an area in need of reform. A framework that is consistent, easy to follow and more founder and investor friendly would have a remarkable impact on the robotics ecosystems and attract the brightest talent from around the world.

9. How can we make it easier to commercialise Australian research and development?

This is perhaps one of the more misunderstood areas of technology transfer. When industry collaborates with academics on research projects, they are accessing the knowledge that has accumulated in these research groups through government investment in fundamental and applied research who then apply that knowledge to the industry collaborator’s problems. The role of research in this situation is to determine if a solution is possible and if so, undertake experimental work to validate a solution. Academics will then hand over the “blueprint” for this solution (proof of concept, prototypes, technology reports) to the industry partner to commercialise. It is important to make the distinction here that universities and researchers are not engineering firms and therefore are not resourced to deliver fully developed, robust products to industry as this is higher TRL activity performed by technical staff. It is our experience that this misunderstanding of the role of research in the innovation cycle leads to the unhelpful impression that there is an issue with academia preventing industry from commercialising research. We are a 90 per cent industry funded research facility, and our industry collaborators have immediate access to the innovations that are born out of these collaborations. Australia has amongst the lowest rates of industry/academia collaborations in the developed world; this creates an entire suite of economic issues for the nation. Incentivising greater industry engagement with research organisations would accelerate knowledge transfer and have profound impact on the broader economy.

We contend that there are also issues with research commercialisation in Australia, however, these mostly involve the university's role in the process and is partly structural and partly cultural. In Australia, IP developed in our universities funded by taxpayer research grants vest with the university. This creates (not illogically) an expectation that the university is entitled to the proceeds of these innovations. In our experience, which is limited to the robotics domain, this is counterproductive as the options available to the researchers to commercialise IP they developed leave them feeling unsupported and often taken advantage of. Researchers are expected to either incorporate outside of the university and pay licensing fees to the university for the IP, leaving aside the issue of charging a new startup licensing fee, if they wish to avoid this they can spin the IP out of the university and the university will take significant equity in the startup, often over 30 per cent. In both cases the researcher is expected to enter a protracted negotiation with the university that can take well over a year. This is not conducive to the needs of an early-stage startup as it forces the researcher into serious legal obligations with a multibillion-dollar organisation before they have even had the chance to explore the commercial viability of the IP. Feedback we have received from entrepreneurially minded researchers is that this approach feels heavy handed and unnecessarily onerous and adversarial, as opposed to the university encouraging and supporting them through an easy, streamlined process to give them the best chance of success.

Another factor in this process is the expectation that a researcher must choose between working in research or pursuing a startup. Why? At the ACFR we have developed numerous different robotic systems we use as research platforms to develop a variety of different technologies. As a result, some of these platforms are highly sophisticated and could be easily deployed on small batch commercial projects. Different universities have different positions on this, many don’t allow it, and the ones that do impose the same onerous processes on the researcher mentioned above. This is an enormous missed opportunity to provide high-value technical staff and researchers the ability to work and gain experience in both worlds. It also prevents access to an additional, non-taxpayer pool of funding for continued innovation and commercialisation and industry exposure to new technologies with a variety of potential commercial applications the researcher hadn’t considered.

This is an area where a National Strategy or government framework that is more entrepreneur or founder friendly would provide transparency and certainty to researchers and universities alike. The rapidly evolving nature of robotics technology means that potential founders need to be given the freedom to move fast. Providing certainty about the process and obligations before the conversation has started would expedite the process and avoid long, drawn out negotiations that are off putting to potential founders.

10. How can we encourage more collaboration between industry and research?

There are a variety of ways the government can encourage industry research collaborations, from minor structural changes, to incentives, to funding.

Government departments oversee a variety of industry support funding schemes such as the recently legislated National Reconstruction Fund, the Australian Renewable Energy Agency, the Rural Research and Development Corporations, to name a few. As has been the theme of this submission, our position is that robotics and intelligent systems offer a fundamental benefit to Australian industry. If the federal government was to adopt this position it could encourage

Australian industries to think about this by making a ‘robotics and automation roadmap’ standard evaluation criteria when accessing industry support schemes. Setting this as a criterion encourages industries to think about ways they can automate their operations, seek advice from experts, or explain why it is not applicable to the application. These initiatives could also consider funding an increased percentage of the applicant's robotics strategy than the typical 50/50 co-investment. These programs are already established, so this minor structural reform to funding criteria would be easy and not require additional investment.

R&D tax credits are an area our industry partners find particularly frustrating as investment in research has a separate evaluation process through the ATO that requires significant investment in time to prepare, is often outsourced to a consultant familiar with the process, and the approval can take almost a year. This seems unreasonably onerous when research is being undertaken with a university and can be easily proven through the contracts and invoices pertaining to the collaboration. Allowing companies to immediately access R&D tax credits for projects with universities would provide a huge incentive for companies to pursue these collaborations. Startups developing hardware and are pre-revenue should be given an equivalent classification, as investment during this phase is almost exclusively product development.

Trust, inclusion and responsible development and use

Trust in autonomous systems is a complicated question that is dependent on the situation and definition. There is trust from the perspective of the roboticist or operator that the system will do what is tasked reliably and safely. There is trust from a civilian perspective should technology become more integrated into mixed use civilian domains like autonomous vehicles. Then there is trust on a societal level, on the impact of increased use within our daily lives and workplaces.

Unfortunately, there is no straight-forward answer to many of these questions. As with any rapidly evolving and disruptive technology there are questions we simply do not have answers to. This is why Trusted Autonomous Systems (TAS) is a rapidly growing field of research interested in several factors contributing to the trustworthiness of autonomous systems, which include but not limited to:

- Robustness and resilience in dynamic and uncertain environments.
- The assurance of the design and operation of autonomous systems through verification and validation processes.
- The confidence the systems inspire as they evolve their functionality.
- Their explainability, accountability, and understandability to a diverse set of users.
- Defences against attacks on the systems, users, and the environment they are deployed in.
- Governance and the regulation of their design and operation.
- The consideration of human values and ethics in their development and use.

It may be helpful to government when thinking trust in autonomous systems is, it is not as simple as creating a list of rules that robots cannot break. How do you tell a robot what the rules are? It is through technology that we can address the underlying sources of distrust and therefore entirely new suites of technologies must be developed to address them. Trust in autonomous systems is a field of innovation in its own right, and by virtue of that, cannot be adequately addressed without investment in research.

For example, in machine learning and reinforcement learning essentially what is happening is the system is trying every possible option to identify the options that work. This obviously does not translate to the real world as an autonomous vehicle cannot drive through a pedestrian strip because it is the shortest route to the destination. The way to address trust is to develop new systems that can contain this experimentation and decision making. Kind of like a sandbox for machine learning. This is an entirely new area of research and innovation, but breakthroughs here will translate to incredible value in a variety of industries and in fact will become industries in their own right. Just as there are OEMs that make airbags for cars, there will be companies dedicated to developing best algorithms for safety and trust. This is an area the ACFR is developing novel tools and solutions in projects funded by the Australian Research Council. Again, fundamental research here will create the breakthroughs that will be the mainstays of future technologies.

This also cannot happen independent of policy and government. In order to develop policies that will inform how these trusted technologies need to perform and vice versa, governments and research groups will need to collaborate to deliver outcomes that provide safety but don't prohibit innovation. The ACFR's current partnership with Transport for NSW is a perfect demonstration of this. Understanding autonomous vehicles on civilian roads is a question of when not if, this collaboration is undertaking research into what that will looks like and how can we develop sensible policy to enable it.

This is perhaps a good way to think about the harder to define impacts and perceptions of robotics in society. Unfortunately, there is a persistent cynicism from the general public regarding robotics systems, that is no small part to do with their portrayal in pop culture and from the discussion paper it is clear the department already understands this. There is a more optimistic message to be sharing with the public, one of positive change and transformation. Greater collaboration between government and research groups that focus on the future of robotics and policy would provide confidence to the public that a sensible approach is being taken to facilitate this transformation and ensure no one is left behind.

Governments the world over have historically been slow to react and regulate to disruptive technologies. This is another area of opportunity for Australia to lead, not just through the delivery of technology, but how to deliver it correctly, in conjunction with good policies and standards, and ensure the benefits to a nation and its people are maximised.

Skills and diversity

16. What are the existing strengths in the skills and capabilities of Australia's robotics and automation workforce? Are there existing or expected gaps that need to be addressed?

Generally speaking, we need more of everybody at all tiers of the technical spectrum. The theme of our submission is that Australia's competitive advantage is the development of high end, complex systems. These are not skills that can be taught in undergraduate degrees and can only be supplied to the private sector through investment in research that produces PhD students.

PhD opportunities are also an excellent way to attract the best talent from around the world to Australia. Having said that, there needs to be an ambitious focus on developing the best talent we have domestically. STEM outcomes in public schools have been trending downwards in recent years and we are seeing this flow through to the Higher Degree by Research cohort where the domestic pool has been shrinking and we often need to look internationally to find the talent we need for projects. The only way Australia can have a sustainable robotics industry is if we have a sustainable pipeline of domestic talent.

This is particularly noticeable on the technical level. At the ACFR, our technical staff are invaluable with a ratio of 1:1 with postdoc researchers. A way to think about this is a researcher will develop a solution or system to perform a task, technical staff will reinforce the solution to ensure it can perform that task repeatedly. This is true for all aspects of robotics, whether it be making a new algorithm robust, ensuring the mechatronic system doesn't break, or integrating a new sensor pack into an existing platform.

As a leading source of both PhD and technical talent in Australia, we can say with certainty that demand is outstripping supply. ACFR graduates are amongst the most sought after in Australia with the highest career outcomes. Enrolments in our undergraduate degrees are consistently oversubscribed which puts tremendous pressure on our existing resources. Without targeted investment to support education and training in these degrees the ACFR, and similar facilities around Australia, will not be able to supply the market with the workface currently being demanded of it. Furthermore, the current PhD stipend are below minimum wage and below the poverty line, in a city with the highest cost for housing in the world. We are already seeing this as a major impediment to attracting the best global talent, or retaining our highest performing domestic graduates when they can earn significantly more in industry immediately. This in even affecting our ability to retain our best post doctorate and technical staff, losing key staff to major projects in the last couple of years.

We are also witnessing an interesting evolution in the state of this technology and the skill level required by operators. In certain sectors its development and adoption is becoming so commonplace that it is now becoming increasingly cost inefficient to continue to hire PhD level graduates who command a higher salary to manage ongoing maintenance and operation of these systems. A push is emerging to integrate many of these complex operational systems into interfaces that can be used by operators with a vocational skill level. This is also true of systems we wish to develop and sell into industries like agriculture where the technology needs to exist to support farmers through intelligent decision making on crop management. It is not a viable strategy for farmers to have teams of roboticists in order to use these systems and consequently much of the work we are doing at the ACFR now revolves around developing systems that can be operated by an someone who is knowledgeable in their particular industry. We expect as demand for these systems grow, so too will demand for undergraduate and vocationally trained roboticists and therefore should be a consideration for future workforce planning.

Encouraging kids into STEM and robotics is therefore an important component of this entire workforce creation. The ACFR has already developed curriculums on agricultural robotics that is taught at high schools in some regional towns with great success. Consideration of a broader primary and secondary school robotics curriculum taught across Australia would be worthwhile.

18. How can Australia improve the diversity of its robotics and automation workforce and better include under-represented groups?

Industries where field robotics are being applied most successfully or have the most potential such as resources and agriculture are located in remote Australia where there is also considerable disadvantage, especially for indigenous communities. The ACFR is a major research partner with these industries, and a leading educational institution. It has long been our belief (and we have pursued this unsuccessfully) that with modest investment we could leverage these relationships and resources to implement robotics curriculums and initiatives in these communities that work with local schools and industry in hopes of providing indigenous kids with clear education pathways into a higher-skilled and paid job in their community.

Another area we have been actively trying to increase diversity is female participation. Female participation remains persistently low across most fields of engineering with the exception of biomedical engineering which is almost at parity. The assumption is that this area of engineering is more appealing to women and is more akin to health and medical research which has greater female participations.

As previously stated in this submission, robotics research for clinical outcomes is an area that is underdeveloped as it falls between existing research funding structures. We believe supporting the establishment of clinical robotics research expertise in Australia through a dedicated funding scheme would be highly appealing to women the way biomedical engineering is and encourage an entirely new generation of women into the field. As the Australian robotics sector grows, other industries would reap the benefits of this through spillover when women inter the jobs market.

Increasing adoption

20. How are businesses and governments adopting robotics technology in Australia? Do they use Australian-made products?

Australia's adoption of robotic systems are variable and industry dependent. As has been stated in this document, our experience of robotics adoption in Australia is that its leans towards the higher-value sectors that require high-quality bespoke solutions; resources, agriculture, defence, advanced manufacturing, to name a few, with Australian suppliers featuring prominently in procurement. While this is something we can all be proud of and is a reason for our excellent reputation, it does also reinforce our position that robotics are not being embraced wholesale in Australia as a key industry enabler and productivity driver.

Through this consultation process the department has indicated it sees robotics being of particular value in certain identified sectors:

- resources
- agriculture, forestry and fisheries
- transport
- medical science
- renewables and low emission technologies.
- Environmental management
- Defence and space
- Manufacturing and construction

There are several points that can be made when thinking about priority areas for adoption. Firstly, we agree that these are areas that Australia stands to gain tremendously through a concerted effort to establish robotics industries around them and boost their adoption. However, we believe that broadening this thinking to consider how robotics technology compliments uniquely Australian dynamics will enable the government to identify areas where increased adoption will deliver additional and significant social and economic outcomes for its citizens.

Australia is a vast land with a small, sparsely distributed population. Australians are highly educated and skilled, and they command high salaries. The Australian content is geographically distant from global supply chains, with a mostly harsh and dry landscape. Every country has a unique matrix of factors, this is Australia's. What is wonderful about the opportunity for robotics in Australia is that robotics mitigates all of these factors to some degree. When we think about robotics for Australia at the ACFR, we think about how these factors are affecting our society socially and economically and how robotics can make a difference. There are numerous examples of this.

Servicing a small population spread across a vast land requires infrastructure that is more expensive with a lower return on investment and therefore more costly and time consuming to maintain. One needs only to travel to regional NSW since the record rains in 2022 to see the poor condition of many essential roads to understand this. In Queensland, regional LGAs recently released a report stating 22,000km or 30 per cent of Queensland sewage and water pipes will be coming to the end of their life cycle in the next two decades, also known as an infrastructure cliff. The inability for government to reprioritise investment away continued expansion to meet the needs of a growing population means that it is mathematically impossible to repair and replace this infrastructure the traditional way without there being significant infrastructure failures. This is not a small or insignificant area unworthy of our attention in a national strategy, the Queensland regional pipe network alone is worth $39 billion. Infrastructure inspection and repair robotics is a rapidly emerging industry that could be utilised here to ensure continuity of infrastructure quality and services in these regional communities. Despite great innovation in this space, these companies find greater adoption in the private sector than compared with civilian infrastructure. Oil and gas, mining, commercial real estate, shipping, to name a few.

Another way these factors affect regional communities is the cost of servicing them. This is largely because it is expensive to transport goods long distances to a small consumer population when a driver is only allowed to drive 12 out of 24 hours. This has a twofold impact, the cost of goods and services is higher for consumers, but it also increases the cost of production for industry, this in turn puts downward pressure on wages. Investment in the development and adoption of fully autonomous regional freight networks that could operate 24/7 would have a completely transformative impact on these regional economies. Furthermore, wholesale automation in regional industries like agriculture would mitigate demand for broad based low skilled labour that the community simply cannot provide instead funnelling the local workforce into higher skilled higher paying jobs. While there is great interest in these areas, adoption is not where it could be if there was a more coordinated effort to support it.

These are just a couple of examples where we see the adoption of robotics ameliorating these uniquely Australian pressures but they are everywhere. When considering where adoption should be prioritised we encourage the government to also consider where there are significant pressures within our system, what is their societal impact and whether robotics solutions could help deliver benefits to Australians.

This brings us to our second point which regards the role of government in driving the development and adoption of robotic systems in Australia. The priority areas identified in this consultation process are mostly areas where government is either the primary stakeholder, end user, customer, or a major stakeholder. Defence, space, healthcare, and environmental management are all areas where government is the major stakeholder and customer, and therefore has the power to be a major driver of adoption in these domains. Modest policy changes within these portfolios that ensure each has a robotics and automation plan supported by a "buy Australian" procurement policy would ensure tendered services are developed, produced and supplied here. A recent example of this at the ACFR was a tender by NSW Train to procure an autonomous defect detection platform for train tunnels. We have submitted a consortium bid with Australian technology providers to develop and produce a completely new robotic platform for this application. We have the expertise and the production capability to deliver this. Under this potential policy, should we be the only Australian applicant, our bid should be successful irrespective of the TRL capability of international bids. The ongoing nature of this procurement would ensure stable revenue for this joint venture to continue to improve the platform and then begin to export to international markets. This procurement scenario occurs frequently in defence and healthcare as well. Government also has significant influence as a stakeholder in transport and energy where these policies could also apply.

The government provides significant support to industry areas such as agriculture and manufacturing through the Research Development Corporations and Industry Growth Centres. The government could ensure that support was conditional on applicants having a robotics and automation strategy with the same “buy Australian” policy. These schemes are already operational and budgeted, so basic tweaks to how funding is accessed and awarded would drive adoption in these priority areas without a major increase in funding.

Some industries we think robotics could enable a major competitive advantage internationally include:

- Agriculture
- Defence
- Healthcare – including assistive devices, surgical robotics, health monitoring, etc
- All tiers of manufacturing and not limited to advanced
- Supply chains and logistics
- Energy – including renewable energy development
- Ship building (and large transport platforms)
- International shipping
- Land based freight
- Heavy industry optimisation
- Space – including in-orbit assembly lunar foundation services and in-situ resource utilisation
- Construction
- Asset and infrastructure management
- Autonomous vehicles

21. Which Australian industry sectors would benefit the most from more robotics and automation? Why?

We believe robotics have the potential to deliver high-value to numerous industries however we have identified eight key application areas that have the greatest potential for positive impacts on society: Transport and Logistics, Primary Industries, Environment, Health and Medicine, Home and Workplace, Emergency Services, space and defence. These areas address issues of global societal concern and have already attracted significant co-investment from industry and government research partners. With the advent of new technological innovation and an increasing focus on the interaction between people, processes and systems, these areas have considerable growth potential in the next decade.

1. Transport and Logistics Application Area

It is widely recognised that we are on the verge of a significant disruptive change in the way that we manage transportation systems and logistics. The aim of the T&L research is to develop and demonstrate the fundamental technologies that will enable the large-scale deployment of future transportation systems. Research will include vehicle-to-vehicle (V2V) and vehicle-to-infrastructure communication (V2I), prediction of driver/pedestrian intent, autonomy, route optimisation, zero emission mobility, planning and logistics. Rethinking the nature of transportation systems and logistics will require consideration of the impact of these changes on economics through the reorganisation of the supply chain, the legal and ethical frameworks required to support mixed mode transportation (driverless and driven) and the skills and educational requirements to support future developments in these areas.

Autonomous Transportation Systems: The next decade will see the introduction of technologies that will significantly change our transportation landscape. This will include the electrification of vehicles, the shift from the petroleum-based economy to batteries and electric motors, and the widespread introduction of driverless technology. Together these innovations will provide for very efficient zero-emission transportation. It is estimated that shared driverless electric vehicles could approach 100 per cent utilisation by providing point to point transportation. This transportation modality will complement current mass transportation systems such as buses and trains, and has the potential to significantly reduce traffic congestion by excluding all private transport from high density areas such as CBDs. This technological revolution will be aided by cooperation and connectivity between vehicles and infrastructure, facilitating optimal scheduling of vehicle availability and allowing for coordination between modes of transport. The combination of these new disruptive technologies will have a profound impact in the way we move, work and interact.

Transportation Logistics: Recent work with Qantas on the Constellations program has demonstrated how fundamental research methods can be applied to develop a transformational platform for fuel optimisation to realise significant operational efficiencies in the aviation sector. The flight planning system developed through this work is based on modern probabilistic planning methods and uses real-time weather information to achieve significant fuel savings. This work, in combination with tools to support predictive maintenance scheduling, is expected to save Qantas in excess of $20m each year on mainline operations through fuel savings. Future work to be supported as part of CRIS will examine requirements for more complex reasoning in air traffic control scenarios and the extension of these methods to other logistical operations, such as rail, shipping and road transportation.

Supply Chain Management: Future supply chain systems will be constantly active: connected through automation systems and platforms as well as wireless communication devices that track goods to provide spatial and transit quality information. This research area will focus on the data fusion and stochastic optimisation systems required to deliver adaptive supply chain systems that constantly meet whole-of-system requirements. Systems like this will be transformative for a large continent like Australia.

Construction: There is great potential for robotics and automation in the construction industry, particularly in the areas of prefabricated masonry, concrete or metal panels, in excavation, concrete finishing and on-site welding. Research in this area will focus both on the application of robotics to construction, and on the efficiencies to be gained through the application of logistics principals to the construction process.

2. Primary Industries Application Area

Australia's economy relies heavily on its primary industries, with mining and agriculture dominating the sector in terms of revenue and labour force engagement. There has been an increasing trend towards automation focused on improving operational efficiency and managing the availability of skilled labour, especially in remote environments. The 'dirty, dull and dangerous' moniker particularly applies to the desire to introduce robotics and intelligent systems in this sector.

Agriculture: One of the biggest issues facing the agribusiness sector arises from the need to support the industry with low-cost automated technologies. Farmers are driving the introduction of this technology because labour is expensive and in short supply, and there is also a desire to improve land productivity while addressing other social and environmental needs. Robotics and intelligent systems will provide growers with greater knowledge concerning the state of their farm and the capacity to manage their crops and livestock in real-time, thus increasing efficiency, reliability and productivity whilst minimising environmental impact. In addition, we need to focus on how future farms will be structured and operate as a whole with autonomous systems. This will require us to educate and manage the transition of current and future agricultural practitioners into the digital age and investigate ways to support agribusiness start-up companies.

Mining: Australian resources sector has been a leading adopter and innovator of robotics technology which has transformed the industry completely. This adoption has been so immense that the future of mine robotics is moving into increasingly advanced areas to manage 'whole of mine' autonomy and optimisation, including areas such as energy optimisation, decarbonisation and field key enabling technologies for automated and remote mining. These include sensing, data fusion, machine learning, machine control and mine systems engineering. Australia has substantive and unique research strength in mining automation technologies and systems with a view to enable automation and optimisation of the entire process from pit through to the port.

Forestry: We have recently begun working with the Department of Agriculture, Fisheries, and Forestry on using Unmanned Air Vehicles to estimate the biomass of wood left following the harvesting of a forestry plot. This work relies on generating detailed three dimensional models using high resolution imagery. Future work will explore how robotics and intelligent systems technologies can be used in the management of plantations, in harvesting operations and in improving land management practices. Things all critical to a sustainable forestry industry in Australia.

Aquaculture: The volume of aquaculture production is increasing rapidly in Australia, and now accounts for nearly 50 per cent of the nation's fisheries production. These operations are largely conducted offshore in dedicated farming facilities. There is a considerable opportunity to enhance these production methods by providing tools to better manage stock, to assess size and mass of fish and to monitor the environmental impact of these operations on the surrounding ecosystem.

Energy: As our economies begin to shift away from a dependence on fossil fuels, we will see opportunities for robotics and intelligent systems to play a role in managing energy distribution and harvesting. The electrification of vehicles will see a significant shift towards distributed generation and storage with Smart Grids required to manage this infrastructure. Novel energy harvesting tools are also in the early research and development phase, including devices for harvesting tidal and wave energy as well as tethered Unmanned Air Vehicles that are able to exploit persistent, high altitude wind energy. Infrastructure maintenance will also become increasingly important as these systems age.

3. Environment Application Area

Robotics and Intelligent Systems will have a profound effect on the way we conduct science, in the gathering of data, in the trawling of that data for information, in the resulting data analytics, and in optimising and conducting experiments. Opportunities here will focus on developing tools and methods for collecting and managing landscape scale data to support studies in the fields of engineering science, ecology, biology, geoscience, archaeology, and industrial applications. The development of survey optimisation methods will facilitate more cost-effective and efficient deployment of multiple, coordinated platforms designed to collect in-situ data that complements information provided by satellite and remote sensing platforms.

Integrated Marine Observing System AUV Facility: IMOS is a nationally coordinated program designed to establish and maintain the research infrastructure required to support Australia's marine science research. It has, and will maintain, a strategic focus on the impact of major boundary currents on continental shelf environments, ecosystems and biodiversity. The IMOS AUV facility generates physical and biological observations of benthic variables that cannot be cost-effectively obtained by other means. We have established an Australia-wide observing program that exploits recent developments in AUV systems to deliver precisely navigated time series benthic imagery at selected reference sites on Australia's continental shelf. These AUV-based observations are providing a critical link between oceanographic and benthic processes for Australia's IMOS program.

Remote Sensing from Continental to Microscopic Scales: The NCRIS funded Terrestrial Ecosystem Network (TERN) has been exploring how remote sensing can be used in modelling and monitoring terrestrial ecosystems. The ACFR is partnered with TERN to explore how in-situ observations taken using sensor networks and unmanned platforms can be combined with broadscale remote sensing data to better understand these sensitive habitats at continental scales.

4. Health and Medicine Application Area

Health and medical robotics program should focus on smart sensing and software for optimisation of medical and hospital systems, medical robotics including those associated with surgery, obstetrics and neurology, intelligent rehabilitation systems, and mobility systems for the elderly and injured. The ACFR has strong partnerships with the Royal Prince Alfred Health Precinct and Charles Perkin Centre to develop next generation surgical robotic suites. Collaborations with industry in this space look to develop innovative medical devices and consider how advances in machine perception, planning, decision making and the construction of novel devices can afford new opportunities in this sector.

Surgical Robotics: Surgical systems are being widely used to conduct minimally invasive surgical procedures. Advances in automated tool stabilization, machine perception and decision making will help to further improve the efficiency and effectiveness of these tools across a wide variety of medical applications. The gradual introduction of levels of autonomy will further enhance the performance of these systems and will allow surgeons to operate more effectively. However, the absence of suitable funding streams robotics in clinical applications limits the capacity to establish serious capability in Australia and leverage unique confluence of high-value resources the sector has to offer.

Assistive Devices for Mobility and Rehabilitation: Advances in both the study of human biomechanics and development of dynamic walking robots are leading to an increased understanding of the roles of sensing, reflexes and feedback control in human walking. This is enabling a new generation of active prosthetic and assistive devices for amputees, stroke victims, and others with restricted mobility. Key research areas include gait modelling and intention prediction, robustness, and energy efficiency.

5. Home and Workplace Application Area

As robotic systems move out of factories and into our personal spaces, we must address issues arising from the close interaction between people and intelligent machines and systems. Human-Robot interaction innovation will explore how people can work comfortably in teams with intelligent robotic systems.

Home Automation: Robotic vacuum cleaners and pool-cleaning robots are becoming commonplace in many homes. These machines are, however, unsophisticated in the types of jobs they perform and the interactions they have with users. As robotic systems are introduced to our homes to assist with more complex tasks, such as food preparation, general cleaning and garden maintenance, serious thought will need to be given to how these robots adapt to the diverse range of situations they might find themselves in. Developing natural interfaces that can be used by untrained people will be a key consideration in the successful introduction of these systems.

Cooperative Robotics: We have seen an increase in the introduction of robotic systems into non-traditional manufacturing scenarios. Flexible assembly and task sharing has appeared recently as practitioners look to enable robots and humans to work closely together, capitalising on the strengths of both.

6. Emergency Services Application Area

Emergency Services applications will focus on intelligent sensor networks and large scale data fusion, data analytics and machine learning for autonomous detection, unsupervised identification of targets or events of interest and rapid response systems using robotics and novel devices.

Bushfire Response: There is evidence that emergency bushfire incidents are becoming increasingly complex to manage, whilst public expectation and government scrutiny of their execution steadily increases. Existing sensing and modelling technologies are able to map and forecast firefront propagation, but planning a response in an uncertain environment is a significant challenge. Development of decision support systems for bushfire response that optimise allocation and routing of resources (people, trucks, aircraft) from across the state to respond to the current state of the fire, prioritising the avoidance of loss of life and property, are all of high relevance to Australia and around the world. The major challenges include inherent uncertainty in a disaster situation, communication challenges, staff fatigue management, and consideration of risk to professional and volunteer firefighters.

Trusted Autonomy: We are currently working with the Defence Science and Technology Group on developing concepts around the area of Trusted Autonomy. A key research focus, particularly in the Security area, will centre on consideration of the ethics and legal frameworks relevant to the changing nature of conflict. As we introduce increasing levels of autonomy in security systems, we must answer questions about the oversight required for these systems to ensure that they continue to follow the rules of engagement. This is a rapidly growing field of research and presents great opportunity for Australia to become a lead developer and exporter of these systems.

7. Space Robotics Application Area

Space is a domain in which robotics plays a natural role, due to the extreme difficulty and expense of manned missions. Space has been the driver for world-class robotics R&D in places such as NASA JPL and Germany's DLR. Until now, Australia has played a minor role in this domain, however the recent formation of the Australian Space Agency and the release of its "Robotics and Automation on Earth and in Space" roadmap and the Trailblazer lunar rover program signals a shift and an opportunity for Australia to play a key role going forwards.

There are major areas of opportunity for Australia in Space Robotics that build on our capabilities in remotely-operated and autonomous systems in the resources sector and marine habitat monitoring (both of which ACFR has made foundational contributions to). In a lunar context, the problems of In-Situ Resource Utilisation (ISRU) and Foundation Services are natural areas for us to focus on. ISRU builds on a large body of research at the ACFR and elsewhere in Australia related to minerals exploration and soil sampling for agriculture. While Foundation Services is centred on autonomous monitoring and maintenance of lunar or planetary infrastructure, which will build naturally on the work at the Australian Robotic Inspection and Asset Management Hub, led by the University of Sydney.

8. Defence Robotics

Defence technologies are already rapidly growing area of robotics for obvious reasons. The desire to remove people from dangerous environments, but also insights and better decision making that can arise from their application to complex, rapidly changing environments. As robotic systems, especially field robotics, begin to take a more dominant role in defence, new scientific hurdles limiting their efficacy will start to emerge. We are already seeing this now through the need better coordination of platforms, data fusion across making multiplatform operations to inform coordinated and intelligent decision making, autonomy and decision making in communication denied environments, multiplatform coordination and decision making in communication denied environments, but also the application of systems we've developed and have experience in from industries like the resources sector have huge transferability. Remote operations, logistics, planning, scheduling, whole of operation optimisation, energy optimisation. Then there are applications in traditional areas of defence with huge opportunities like in ship building and shipyard optimisation for the Navy which we have mentioned above. Incredible innovations and new supporting industries could come out of this alone.

These are all areas Australia has immense talent to apply effectively. Defence technologies by its very nature must be the most advanced for it to be effective against potential aggressors, as a deterrent, or in contested situations. Defence research for this reason often has a strong focus on fundamental research. Unfortunately, the Australian Defence Force has not taken advantage of the competitive edge they have access to in robotics systems research expertise. The ACFR has for some time now attempted to engage with the ADF and the service providers to establish a stronger, deeper relationship akin to that of the DoD and MIT through the Lincoln Labs in the US but have been unsuccessful. Frustratingly, we see how the absence of such a partnership is actually costing the ADF more than it should as the service providers often have the same needs and will release EOIs asking for the same technology, coordination between autonomous platforms is one example. Better coordination and engagement between the ADF and Australian robotics research expertise would enable Australia to develop a sovereign defence robotics industry on par or better than the current leaders. This is an enormous opportunity that is not being properly accessed.

22. What are the barriers to increased adoption of robotics and automation? How can we address these barriers?

Awareness is a significant barrier for adoption. The persistent negative perception of robotics within broader society limits the dialogue about all the potential benefits that Australia specifically stands to gain from greater adoption of this technology.

Another is the risk involved in developing high-value but bespoke solutions for an industry segment. Hardware development is expensive, so despite there being a clear and definable need, the expertise to develop a solution, and customers willing to purchase the technology, the fragmented nature of most industries makes resourcing a solution difficult.

This is in part why the resources sector has been so successful in this space. The sector is dominated by major players making innovation investment modest relative to their size. Many resource companies will develop their own unique solutions and manage them in-house as off-the-shelf solutions do not exist. This is different to other major industries like agriculture, healthcare, freight, etc, that are comprised of a larger number of smaller competitors who might want to develop a novel solution but do not have the capacity to manage its ongoing maintenance in house. *'Farmers are not technology companies'.* In these instances, coordination, possibly through government schemes like the RDCs, would enable the delivery of off-the-shelf solutions to a greater number of stakeholders.

These dynamic repeats all the way down as industries atomise into smaller and smaller potential customers, and is why Boston Dynamics, or any of the amazing Australian robotics startups do not target the B2C consumer market. The robotics industry Australia has and should aspire to grow will not produce one size fits all robotic systems in the near term, every new application will require some level of investment to make it work in that setting and that requires coordination and support if we are to supercharge adoption.