NATIONAL MARINE SCIENCE COMMITTEE

Engineering, Prototyping and Technology Development – Robotics, Autonomy and Automation

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1. Abstract

Technology Development, Engineering and Prototyping (TDEP) is a cornerstone for healthy economies and prosperous nations. Australia has not invested in technology research and development sufficiently over the last decade leading to concerning trends in economic indicators such as economic complexity. While Australia is world-leading in research outputs, these are not translating to commercialisation of new products and services at a rate commensurate with other developed economies.

Australia is a marine nation with a world leading marine science industry. Without focusing efforts on the underpinning technology and tools supporting this industry, our nation's ability to keep pace with marine science needs will continue to fall behind. Australia will continue to be consumers of new technologies and tools rather than developers and exporters of such systems.

Observations in Australian waters remain extremely sparse and increasingly lag global marine observing trends. As such, progressing the understanding and management of Australia's marine environment and the science that underpins its management is increasingly dependent on the progress of technologies that enable marine observations. Investment in engineering, prototyping and technology development within Australia is an important step towards supporting and growing domestic and regional observations.

A multi-faceted approach is required to transform the marine technology capability available for Australia's marine science industry. In this paper, we propose 6 areas for action:

1. TDEP initiatives
2. Coordination and Collaboration Frameworks
3. TDEP Infrastructure investment
4. Futureproofed Workforce
5. Evolving Regulatory Frameworks
6. National Technology Policy

2. Relevance - Societal Benefits

Australia is a marine nation with a vast ocean territory of over 8 million square kilometres that stretches from the equator to the Southern Ocean and is crucial for sustaining our economy, environment and societal well-being. Management of Australia's exclusive economic zone (EEZ) requires investment in marine science underpinned by robust observations. However, achieving comprehensive observation regimes to support management of such a vast and diverse marine domain has unique technological challenges.

Advancements in marine technology and engineering are essential in addressing Australia's observation gaps and in preparing the innovation system to better support changes in observing trends into the future. Moreover, investment and advances in marine technology development create economic opportunities to grow domestic industry, bolster sovereign supply of critical observing technologies, and enhance Australia's standing as a global partner of choice.

TDEP translates scientific knowledge into new tools, products and technologies. It's a centrepiece for innovation that has the potential to strengthen Australia's economy and long-term prosperity. By investing in TDEP, Australia will be able to capitalise on its world leading research by facilitating the commercialisation of new technologies into products and services.

Globally, technological innovation in the marine science field have stagnated, thus sometimes decades old solutions and sampling strategies are being used to collect Australia's core datasets. These legacy technologies cannot scale to meet current observing trends. Investment in new observing solutions is required to scale the coverage and capabilities that would support routine marine sampling in Australia. These investments need to be futureproofed and sustainable, capitalising on coordinating our existing capacity while simultaneously investing in capability gaps.

Marine technology investment enables more and better observations that will in turn drive improved marine ecosystem predictions central to future decision making. All elements in the marine science chain benefit: from researchers to operators to data users. Technology provides a feedback loop linking data users to researchers, allowing continued optimisation of solutions and subsequent datasets.

Direct Beneficiaries:

- **Marine Scientists and Researchers**: Enhanced technology and engineering capabilities provide improved tools for data collection, analysis and interpretation, leading to more accurate and comprehensive scientific findings.
- **Blue Economy**: Improved monitoring and management of marine resources ensure sustainable practices, boosting productivity and economic sustainability.
- **Coastal Communities**: These communities' benefit from better protection against coastal erosion and extreme weather events through advanced engineering solutions. Improved access to information flows through into recreational and commercial activities.
- **Domestic Marine Technology Providers**: These are provided more opportunities to leverage domestic R&D developments into commercial products.
- **Policy and Decision Makers**: These have a direct benefit from more current, accurate datasets with more traceability and ability to scale. Technology also enables integration with AI and automated workflows. These can be interlinked with dashboards to provide near real-time updates for decision makers to identify early warning signals and track progress.

Indirect Beneficiaries:

- **General Public:** Healthier marine ecosystems contribute to better air quality, climate regulation / forecasting, and recreational opportunities.
- **Australian Economy:** Foster and grow Australia's blue economy.
- **Global Community:** Australia's advancements in marine science can serve as a model for other nations, promoting global environmental sustainability.

Closing the marine observing gap in Australia presents many challenges but also opportunities.

Challenges:

- Supporting technology development across Australia's diverse marine regions extending from the equator to the poles and from coastal waters to the deep ocean. These regions include some of the harshest marine conditions on the planet.
- Limited domestic access to marine technology development facilities.
- Difficulty in attaining regular access to marine areas for testing and development of marine technology.
- Nation-wide issues in skills shortages and TDEP investment impact the marine science sector
- Regressive and restrictive regulatory environments limiting the development of emerging technologies

Opportunities:

- With its diverse environments, Australia is a great testbed for marine technology.
- Australia has a highly skilled workforce and strong research institutions that can help support a growing marine technology industry.
- Beyond marine science, these capabilities can be applied across the Blue Economy including offshore renewable energy (e.g., offshore wind farms), as well as developing disaster resilience, extreme weather prediction, and national defence.

Stakeholder Needs

In Australia, stakeholder requirements for marine technology, development, engineering, and prototyping are shaped by the need for clear roadmaps that align innovation with scientific, industrial, and policy priorities, supported by foresighting and adoption planning. Regulators such as AMSA emphasise transparent, risk-based frameworks for emerging autonomous systems, requiring technology developers to ensure compliance through robust safety and communication systems. Strong national coordination across research institutions, universities, and government agencies is essential to maximise investment impact and foster translational outcomes, while industry partners demand adherence to recognised standards and reliable prototyping infrastructure to ensure scalability and credibility. Environmental agencies and research bodies require alignment with national marine science strategies, sustainability goals, and climate resilience frameworks, while community stakeholders—including Indigenous groups and fisheries—expect early engagement and co-design to build trust and secure social license. Defence stakeholders, meanwhile, prioritise rapid, agile prototyping that delivers “minimum viable capability” for urgent operational needs. Collectively, these requirements highlight the importance of collaboration, compliance, and adaptability in advancing marine technology innovation in Australia.

Current capabilities in TDEP in Australia are robust, but face limitations in addressing emerging challenges. While there is significant domestic expertise, gaps remain in infrastructure investments, engineering research coordination/collaboration, integrating advanced technologies, technology commercialisation/partnerships, regulatory challenges and ensuring comprehensive stakeholder engagement. The sector is largely fragmented across various research institutions, universities and government, with relatively little coordination among agencies. Few facilities exist for sharing best practice or access to specialised equipment and services across institutions, particularly for newly developed technologies. Access to the latest technologies and methods is largely achieved through leveraging international partnerships which limits access and does not always address Australia’s specific needs. Enhancing capabilities through investment in cutting-edge technologies, interdisciplinary research, and international collaboration is crucial to meeting evolving needs. Pathways to engage indigenous perspectives into the technology development, engineering and prototyping processes in Australia are also limited. Engagement is currently focused on users of the technology and through uptake of data generated.

3. Current “State” of TDEP in Australia and globally

Despite the marine industry generating $118.5b in output in 2020-2021 [2], in that year the total Australian government R&D investment was $3.618b with little to no investment in marine TDEP. While the Global Innovation Index 2024 report ranks Australia 23rd on gross expenditure on R&D, investment in Australian R&D has not maintained parity with inflation, with only 0.4% growth from 2011-2021 [3].

As shown in Figure 1, globally, Australia ranks highly with respect to measures such as university quality, research paper production, citations and university-industry R&D collaboration. Australia ranks 84th globally in graduates in science and engineering which is contributing to growing workforce challenges. Australia also ranked 91st globally for economic complexity, indicating less sophistication and diversity in product exports and therefore production capabilities. This forms one of the key issues facing Australia with respect to its capacity to translate research into commercial products.

With the global political landscape changing, venture capital investment also dropped by $2.09m USD in 2023, down 50.94% from the year prior. The 2024 Global Innovation Australia report [3] highlighted a 14.3% reduction in international patents filed from 2022 to 2023. In response to COVID supply chain issues and the subsequent national focus on sovereign capability, the Australian Bureau of Statistics shows that in 2022-2023, the Australian government injected $4.344b (increase of $726m in 2020-2021) or 0.17% GDP into R&D and 15,889 R&D employees (increase of 842 personnel from 2020-2021) [4]. This investment was a useful accelerator, however, sustained investment is required to improve Australia's R&D capability and subsequent technological commercialisation in the long term.

While engineering dominates Australia's science, technology, engineering and math workforce, representing 80% of the VET STEM workforce and 38% of the STEM labour force, Australian high school students studying higher level mathematics (prerequisite to university engineering) has dropped to an all-time low of 9.2% [5]. Similarly, domestic engineering enrolments have trended downwards since 2014. This downward trend of domestically trained engineering and technical staff directly impacts all Australian sectors including marine science.

While there are pockets of excellence in research across the country, investment in technology development for marine science is not a national focus. There are clear trends showing a decline in the number of engineers [6] and technicians [7] in Australia driven by retirement and insufficient new professionals. Enrolments into technology development, engineering and prototyping disciplines at the university and vocational level are also falling. When coupled with limited succession planning in marine science organisations, Australia is at great risk of not having the skilled technology workforce needed to meet marine TDEP needs.

At present there are not sufficient numbers of university or TAFE candidates in technology, with a noted decrease in apprenticeship and other training opportunities in the sector. This is a broader trend than just the marine science sector, however, there is minimal work nationwide to address this problem for the marine science industry.

Figure 2 shows Australian Government R&D investment by top 10 Fields of Research. While many of these fields of research support marine science, it is not a strategic priority and therefore marine science only secures a fraction of the above investment for its purposes. Instead, the technology development focus tends for be on integrating and applying existing technologies from other areas and adapting them to marine use cases.

Overview of National Technology Initiatives and Investment in Australia

While technology developed and applied in the marine science sector is lagging, as a consequence of COVID and the changing international political landscape, Australia has recognised sovereign technology development as a key risk to our nation's sustainability. The marine science technology sector could strategically manoeuvre to take advantage of these investments.

Australian Government committed $22.7b over 10 years through the Future Made in Australia Act [8], which establishes a framework for significant investment to make Australia's economy and energy sources more resilient in the current state of global change. Funding unlocked through this scheme should support renewable energy and sovereign supply chain initiatives.

Table 1: Australian Critical Technology Sector Snapshot

Technology Sector	Number of Aus Companies	Foreign Investment (last 5 years) ($b)	Venture Capital Investment ($b)
AI	650	7	2
Advanced ICT	5535	19	-
Advanced Manufacturing	Unk	4	2
Autonomous Technologies	180	95	2
Biotechnologies	1400	933	-
Clean Energy	364	56	2
Quantum	18	-	600

Advanced manufacturing has minimal comparative investment. Autonomous technologies have attracted significant ($95b) investment over the last 5 years with a relatively small number of Australian companies (180). Conversely, AI has 650 companies with a modest foreign investment of $7b. The large foreign investment in biotechnologies (Table 1) is driven by the health sector.

Australia is actively addressing national critical technology gaps through planned multi-year national investment, national policy creation, and intentional international partnership creation. Plans and Initiatives are being released addressing the technology sector with potential impact on the marine science industry including:

- Future Made in Australia Policy [8]: $22.7b investment into sovereign technologies over the next decade
- National Reconstruction Fund (NRF) [9]: $1b financing allocated for critical technologies projects [9]
- AUKUS Australian Investment [10]: Billions of funding, where AUKUS Pillar 2 is of relevance to marine science

A lack of focus and awareness of parallels with the marine science sector has translated to a lack of benefit-uptake in the marine science sector.

While Australia has developed some competitive technical capabilities in a range of marine technology areas, there have been limited opportunities to connect and share IP across the Australian innovation system and translate these developments to industry. Primarily this is driven by lack of investment and funding opportunities to support industry investment in non-defence TPED applications. The current key players influencing technology development, engineering and prototyping in the marine sector are shows in Table 2.

Table 22. Australian Marine Science Technology Development, Engineering and Prototyping Landscape

Select Marine Science Technology Development Entities	
Academia	Uni Sydney (ACFR), UTAS (AMC), QUT (Centre of Robotics), University of Queensland, Curtin University, Flinders University, University of Western Australia, Charles Darwin University, Deakin University, Griffith University, University of Melbourne, University of Tasmania, Southern Cross University, James Cook University
Research / Government Organisations	IMOS, CSIRO, AIMS, SARDI, AAD, DCCEEW, SIMS, Defence (including DSTG), Parks Australia, BOM, Blue Economy CRC, TASDCRC, AMC Search, ARC Centres of Excellence, NCRIS, FRDC, GBRMPA, State Governments, SICA, SmartSat CRC, UWA (IOMRC)
Australian Industry	Advanced Navigation, Ocius, GreenRoom Robotics, Thaum, FrontierSI, Reach Robotics, Jasco Applied Sciences, Blue Zone Group, Greybits Engineering, GeoOceans, Austal, The Whiskey Project Group, Fugro, Blue Ocean MTS

Comparison with Other Nations

Australia has a minimal portion of the research market share in critical technologies at the international level. Initiatives such as AUKUS have great potential to upscale the technology development and research sharing potential available to Australia's marine science sector. Data on marine TDEP investment is not readily available. Figure 3 shows Australia's relative research contribution to AUKUS related areas and is a good representation of Australia's contribution relative to international partners.

Critical Technologies and Technical Maturity

Australia's critical technology statement outlines high priority technology areas. These technologies are application agnostic. A Technology Readiness Level (TRL) assessment in relation to these technologies as applied to the marine science sector is detailed in Figure 4.

Technology investment is typically focused on the adoption of off-the-shelf devices for use in marine science rather than on the development of systems from the ground up. This is largely due to the inherent risk associated with technology development activities and the relatively small market size represented by the marine sector. However, Australia's marine environment is unique and diverse. Investment in technology development can produce solutions that will strengthen both our solutions and sovereign supply chains.

Development Trajectories and International Trends

There are five global trends driving changes in marine observing summarised in Figure 5. Marine observing solutions are increasingly required to be adaptable, multi-disciplinary, wholistic and provide the ability to scale. These trends are driven by increased demand in marine observations, and stagnant global funding resulting in increased pressures to improve return on investment in marine science operations. Researchers in Australia have contributed a range of technological solutions to meet this challenge, one of which is the development of autonomous sampling. Autonomy is the future of marine observations, a key enabling technology in addressing global observing trends, and an important area of investment for marine TDEP.

Australia's Position by 2035

Under current scenarios, Australia's position in marine science technology and capability by 2035 will diminish due to stagnant investment in engineering capability with research institutions, limited capital investment in marine TDEP infrastructure coupled with the accelerating pace of change in future technology enabling areas such as marine autonomy and AI. The lack of significant commercial sovereign supply of marine technology reinforces long-standing dependencies on international partners at a time of increased geo-political instability. Subsequently, access to the latest technology to support Australia’s marine observing needs may be at risk.

Technology development funding streams in the marine science sector have not kept up with inflation, facilities are aging and approaches are stagnating. A holistic, collaborative, national approach is needed to change Australia’s trajectory towards 2035. This process must build marine science to leverage into Australian technology development initiatives, while supporting the sustainable growth of facilities, workforce, collaborations and knowledge & facilities accessibility.

4. Investment needs

The technological capability and infrastructure needs supporting Australian marine science are diverse and require a policy-driven approach involving both top-down direction from government agencies and bottom-up engagement from industries and researchers. Six areas of action have been identified to strengthen Australia’s TDEP in supporting future needs. These actions should be taken in a parallel and in a coordinated fashion.

The establishment of a National Centre of Marine Technology (NCMT) could enable the distribution of funds, coordination of research activities and facilitate access to key TDEP infrastructure across the country.

1. **TDEP Initiatives**:

   Investment in TDEP initiatives for marine science needs has been lagging due to lack of dedicated funding and inherent risk associated with technology development combined with Australia’s unique and challenging operating environment. Targeted investment for technology development supporting marine science applications is needed at the national level, with a contracting process aligned to maximise investment partnerships. Dedicated funding should be made available through the NCMT and coordinated with new and existing initiatives to support directed multi-year technical development. This funding could also be leveraged to grow partnerships with industry, support technology translation, and assist in proof-of-concept evaluations. Funding should also support both large and small projects across the TRL scale. To gain critical mass, it is proposed that capability gaps be explored by leveraging existing federal technology investment programs and capabilities.

   Additional investments in marine observing will also drive demand which strengthens the business case for marine science technology investment; see the infrastructure white paper. Opportunities for partnerships between TDEP providers and existing marine infrastructure investments such as the Marine National Facility and ReefWorks will further support growing TDEP investments. While TDEP investments will look to develop tools to support marine observations, it also has the potential for research generation and associated data uptake as a direct result of the technology development.

2. **Coordination and Collaboration Frameworks**

Technology development, engineering and prototyping expertise is dispersed across the country. It is characterised by pockets of excellence in niche areas across industry, academia and research organisations, but no routine way to share capabilities and knowledge, coordinate activities or readily collaborate on projects exists. Varying approaches to research IP management, and the ability to translate research IP to industry creates difficulties. Furthermore, Australian technology development expertise is often delivering solutions to non-marine science sectors due to the current lack of funding, drive and awareness of marine science's needs and challenges.

A national forum should be established to bring together leading marine technology agencies to develop forward plans to develop marine technology investment, coordinate research priorities, pool resources, and help address operational challenges such as IP sharing. This group should – along with other agencies and sectors in Australia – host technical workshops and conferences as a means to share research outcomes and best practices, and coordinate high level engagement of Australian institutions with international planning efforts; such as the international marine science and technology conference and planning group OceanObs'29. Efforts should also be made to engage in related research sectors (i.e. defence, space etc) to ensure any technology overlaps can be identified. Funding could also be used to support the establishment of grand challenges (i.e. X-prize) to further encourage industry / research collaborations.

3. **TDEP Infrastructure Investment**

Investment in infrastructure supporting marine TDEP is modest, irregularly distributed across the nation, and not maintained to compete with international best practices and emerging technologies. Required infrastructure to support marine TDEP includes:

- Prototyping and development facilities: electronics labs, chemistry labs, rapid prototyping facilities, materials labs
- Specialised manufacturing facilities and workshops that can produce goods suitable for deployment in marine environments.
- Metrology facilities for marine instrument calibration, testing and development.
- Coastal vessel fleets to support technology development and testing needs.
- Environmental testing facilities including, pressure testing facilities, marine environment simulators (both physical and digital)
- Marine testbed areas (i.e. ReefWorks) in coastal and deep waters which are instrumented and monitored to enable prototype evaluation in real-world conditions.

Investments in existing and new infrastructure across Australia is critical to facilitating engineering developments. These facilities should be developed to support development across the innovation system and facilitating access by both research and commercial entities looking to develop and test their projects. Funding should be provided on a long enough time scale to support facility setup and updating as technologies and needs evolve.

4. **Futureproofed Workforce**

There are clear trends showing a decline in the number of engineers [6] and technicians [7] in Australia driven by retirement and insufficient new young professionals to meet growing demand. Enrolments into technology development, engineering and prototyping disciplines at the university and vocational level are also falling. When coupled with limited succession planning in marine science organisations, Australia is at great risk of not having the skilled technology workforce needed to meet marine science needs. This challenge is broader than the TDEP sector, however there is minimal work nation-wide to address this problem for the marine science industry.

Pathways for future marine technician and engineering specialists in Australia requires a concerted effort to resolve. Research instituted needs to further engage with engineering and technical disciplines to broaden the appeal of the field. Flagship research projects funded as part of action 1 would help inspire young professionals to join the field and to see Australia as an exciting place to build a career.

National marine technology competitions in marine areas would also serve to further engage students in the field and establish pathways for students to build relevant work experience during their studies. Vocational, apprenticeship and other hands-on training programs should be encouraged and adequately funded by state and local governments.

5. **Evolving Regulatory Frameworks**

Existing regulatory frameworks in Australia have failed to keep up with the latest technological developments and have proven inflexible in adapting to the needs of the marine TDEP communities. In particular, regulation around the development and use of autonomous technologies in marine and air domains have significantly hindered the proliferation in both development and use of these systems in Australia. In many cases, commercial and research activities in these areas have moved out of Australia to other nations that have proven more flexible in addressing their needs.

Marine science needs to ensure that our needs and roadblocks are addressed as the regulatory environment evolves to cater for new technology. Regulatory impacts extend from communications control, approval to operate and approval to export. These require contributing to national forums and intentionally injecting our requirements into discussions with appropriate regulators. This can be achieved through community groups such as AAUS and AMSA, or at the federal and state government level. Test ranges can play a part in road-testing proposed regulatory controls in order to build trust with marine science organisations.

Regulators should be urged to work with government and university research organisations to explore options to enable the development, testing and integration of new technologies in the marine domain. National laws need to be updated to empower regulators to allow for flexible fit-for-purpose approaches to new technologies in partnership with developers to enable safe, efficient and easy use of technology in Australia. This can be achieved through the establishment of formalised partnerships between and access to research organisation expertise. Modernisation of regulatory approaches would not only allow Australia to remain competitive in the development of marine technology, but encourage investment in regional and global technology companies to invest in Australia.

6. **National Technology Policy**

The UN Ocean Decade Challenges have demonstrated the importance of marine science at the international level. Australia's technology policy, critical technologies or subsequent national investment in technology development, however, have not kept pace. Despite recent national plans such as the Sustainable Ocean Plan [12] referring to Innovation and Technology, the lack of marine technology-centric policy and prioritisation across government sectors present challenges to raising the profile and importance of marine TDEP investment.

Departments with marine science portfolios must be made to raise marine science's significance on the national technology agenda through the incorporation of marine science priorities in national technology policy. In particular developing pathways for collaboration and investment across technology sectors will allow the nation to better address marine science challenges.

Additional Barriers to TDEP Capabilities

In addition to the capability gaps listed, a significant cultural barrier exists for technology development, engineering, and prototyping in marine science. There is a lack of understanding and appreciation of the importance of technology development and applied technology evolution in the marine science sector. Tried and true methods tend to exist for decades while other industry-driven sectors have adopted generational changes in technology. This creates large gaps between industry best practice and capability, and what toolsets marine researchers are aware of. Until the culture changes to one of early adoption and of proactive experimentation with new tools, marine technologists will face continued resistance in applying technologies in the marine science domain.

Several barriers could prevent research and development (R&D) at the required pace and scale. One major barrier is the lack of observational platforms with larger payloads capable of monitoring a wider range of environmental and ecological parameters. Improvements in technology that allow for longer deployments, such as bigger batteries, more energy-efficient systems, and more stable sensors, are necessary. Additionally, developments in machine learning to assist signal detection, characterization, and abundance estimation for marine fauna, as well as soundscape characterization, are needed.

Another barrier is the need for sensor development. Access, capital expenditure, calibration and on-going maintenance costs often inhibit widespread sampling of many datatypes. Investment in the development of low-cost, calibrated sensors as well as standards for owner-based calibration (rather than manufacturer or specialist calibration centres) are needed, such as those under development for hydrophones that record Ocean Sound (e.g., IQOE Low-cost Hydrophone WG). Improvements in on-board processing, connectivity between sensors (swarms) and through satellites, and greater standardization in sensors, methodology, and reporting for many datastream (such as for Ocean Sound pressure and particle motion) are also essential. More accessible test arenas for equipment and a greater number of deployment platforms around Australia are required to support R&D efforts.

National Partnerships

National partnership initiatives such as IMOS are essential in collating Australia's marine observing needs and challenges to ensure technology development investment aligns with current and emerging priorities. The establishment of an NCMT focusing on technology in the marine science domain is needed to bring a focused effort between Australia's technologists in addressing marine technology needs and challenges.

Policy partnerships at a national level will allow Australia to align its marine technologies with global conservation and sustainability targets. Government funding, such as ARC LIEF grants and Linkage Infrastructure, Equipment, and Facilities, is crucial to support large-scale projects and infrastructure development. Increased private sector involvement from industries like offshore energy, shipping, and fisheries, can also play a significant role particularly when driven by policy.

International Partnerships

Australia relies heavily on international partnerships to develop, integrate and apply technological solutions for marine science. Over many decades, Australian researchers and institutions have fostered strong technical collaborations across Asia, Europe and North America, and allowed Australia to benefit from technical investments overseas. The international landscape, however, has changed dramatically over the past five years due to the impacts of COVID, uncertainty in supply chains, and increasing geo-political volatility. These changes have had a lasting impact on Australia's marine technology development initiatives and have highlighted vulnerabilities arising from the strong inter-dependency with partners.

International collaborations will continue, but will be increasingly scrutinised (particularly with US agencies) with a need to be target-driven. Broad information sharing of best practices, smaller jointly funded research projects and data-sharing agreements for marine monitoring and conservation efforts may continue to varying degrees. For example, collaboration with the offshore wind industry in Europe can provide insights into best practices for long-range uncrewed marine observing technologies.

Australia's national contribution to international marine observing initiatives such as GOOS, ARGO, WOCE and other international sustained observing programs is lagging behind our peers. A concerted effort should be made to contribute to these programs where possible and share our data routinely to internationally recognised datasets from both a data dashboard and data repository perspective.

5. Progress/Impact Measurement

Measuring the impact of engineering, prototyping and technology development is complex and multifaceted. As an enabling function, it contributes to the data available, the efficiency of its collection, processing or integration, and the ability to scale. Solutions are developed to address an existing or emerging information gap. Progress and impact are therefore measured through, successful acquisition of data, metrics against the challenges the technology was developed to solve, as well as technology lifecycle metrics including ability to evolve and solution sustainability.

Suggested metrics of the impact of the engineering, prototyping and technology development on marine science itself are listed below:

1. **System and Data Uptake**: Data uptake is the traditional metric for assessing the success of a data acquisition method. The generation of datasets by new technologies and subsequent uptake by diverse audiences continues to be a metric of impact for underlying technologies. With improved connectivity, these datasets could be integrated to new dashboards and generative-AI tooling to provide more linkages with potential future users of the data, with dataset visualisation or access hits providing more uptake metrics.

2. **Addressing of data gaps**: Technology development is often aimed at addressing a gap in observable data. Impact can therefore be measured by data collected in new geographical

areas, of new observations (through new sensors) or at new time resolution (more frequently, over longer periods etc). For reactive sampling technologies, impact could also be measured from improvements in the time delay between an event and an in-situ observation.

3. **Ability to scale**: Technologies need to consider the large geographical expanses of Australia in order to encourage uptake in marine science. Technology investments must consider simultaneous sensing and diverse deployment environments across widely-ranging spatial scales. Impact metrics could include diversity of deployment locations, ability to take observations in locations currently out of reach, or ability to contribute to cumulative marine science fields through deployment in multiple scenarios with multiple sensors simultaneously. Another useful metric of impact is cross-domain scaling of the technology – is technology developed for marine science being applied in other sectors, thereby increasing economies of scale for the technology development.

4. **Safety**: New technologies must either maintain or improve safety metrics of current marine observations. Safety of the technology itself and of improvements it brings to its deployment environment (e.g., deploying robotics in crocodile infested waters instead of human-based surveys) are essential considerations in measuring impact of the system. AMSA safety incidents in the field in marine science activities could be one example measure.

5. **Return on Investment**: Investing in technology development can be for the purposes of generating cost efficiencies against current methods, but this should also be considered a design goal. The impact metric would be a quantitative measure of data acquisition cost when compared to other methods. Depending on the technology and intent, this could be by deployment, by sample or by whole-of-life cycle assessment. Another important metric here is uptake versus the initial technology development investment.

6. **National Technology Policy**: Metrics to track the impact of integration of marine science into national technology policy include:
    1. <u>Influence</u>: Marine science technology stakeholders on advisory boards for critical technology policies such as Future Made in Australia and AUKUS.
    2. <u>Awareness</u>: Marine science technology listed in national technology policy documents
    3. <u>Investment</u>: Either directly or through dual-use solutions, an increase in funding invested in TDEP applied to marine science applications.

6. <u>Dependencies and Priorities</u>

Marine science in Australia typically leverages existing established technologies to deliver observations with a low-risk appetite to evolve to new technological solutions. Routine data collection methods largely rely on in situ instrumentation and diver-based observations with sensor systems pre-dating advances in Internet-of-Things connectivity, automation and modern modular design approaches. Existing technologies are coupled with sampling strategies to create routine datasets. Injecting a step-change through technology requires validation studies with prior datasets and a holistic approach.

Marine autonomy is the critical new technology enabler that will drive a seed change in Australia's marine observing landscape. Autonomy in both platforms, planning and analysis of data promise to deliver significant scale improvements to existing operations and address the prescient challenges faced by marine observations in Australia. Supporting and growing technical developments in autonomy will require investments in infrastructure (as outlined in Section 3) to support development and testing, investments in projects and changes in regulatory structures.

In addition to autonomy, technology is progressing in other related disciplines that should also be supported, most notably in biological sensing (see eDNA WP). Space communications and consumer-sensing empowered through smart devices are examples of modular technology reshaping researcher's understanding of what is possible. Recommended elements are listed below.

1. **TDEP Investment**

   Targeted investment in addressing technology development, engineering and prototyping, commercialisation and industry support needs, is required at the national level for marine science. The quantum of investment in initiatives at the national level should be on the order of $30M AUD annually with co-investment from government and industry.

2. **Coordination and Collaboration Frameworks**:

   Australia's technology community in marine science technology is small with expertise in various niches. An annual marine technology symposium focused on Australia's marine science use case, but attended by experts in technology applied to the marine domain (cross-domain application) is proposed as a first step. Events can be managed on a cost-recovery basis but an investment of $100K AUD per year would support co-ordination.

3. **TDEP Infrastructure Investment**

   As technology and societal expectations evolve, Australia's infrastructure also needs to evolve. This should be targeted to meet key gaps, evolution needs and meet cross-sector (beyond marine science) demands where possible. In a similar way to NCRIS, this would be a focused investment to build on marine science needed infrastructure adaptation needs. A full scoping of existing capabilities is required to capture this cost but assuming a centralised uplift across three sites in Australia with minor investments in a few others would be on the order of $100M AUD.

4. **Futureproofed Workforce**

   Pathways for future marine technician and engineering specialists in Australia requires a concerted effort to resolve. In addition to funding flagship development projects, an investment of $1M to setup a recurring student competition would support engagement of students in marine technical fields.

5. **Evolving Regulatory Frameworks**

   Marine science needs to ensure our needs and roadblocks are addressed as the regulatory environment evolves to cater for new technology. These requires contributing to national forums and intentionally injecting our requirements into discussions with appropriate regulators. This can by through community groups such as AAUS and AMSA, or at the federal and state government level. Test ranges can play a part in road-testing proposed regulatory controls in order to build trust with marine science organisations.

6. **National Technology Policy**

A focused effort between Departments with marine science portfolios must be made to raise marine science's significance on the national technology agenda. This will create investment pathways through synergies with other Australian technology development initiatives such as AUKUS and raise awareness of marine science technology challenges and needs.

7. Conclusion

While Australia has developed competitive technical capabilities across a range of research, government and industry organisations in a range of marine technology areas, there have been limited opportunities to connect and share IP across the Australian innovation system and translate these developments to industry. Primarily this is driven by lack of investment and funding opportunities to support industry investment in non-defence TDEP applications. Advances in ocean monitoring technology will play a central role in transforming marine science over the next decade. Australia through its geography, integrated innovation system and technical workforce is uniquely placed to contribute to the global marine technology landscape with a strong pull from key stakeholders. Technology advances will not only accelerate marine and climate science research but will have secondary benefits in boosting the tech economy through technology investment and uptake. These benefits are, however, contingent on thoughtful, timely and coordinated actions and strategic investment across the sector.

A multi-faceted approach is required to transform the marine technology capability available for Australia's marine science industry. In this paper, 6 areas of action are recommended to enable sustainable growth and secure the future of marine technology in Australia. These include targeted TDEP investment, coordination and collaboration frameworks for marine technology development, investment in critical infrastructure, developing futureproof workforces, evolving our regulatory environment to accommodate new technologies and evolving our national technology policy.

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<u>Supporting Graphics</u>

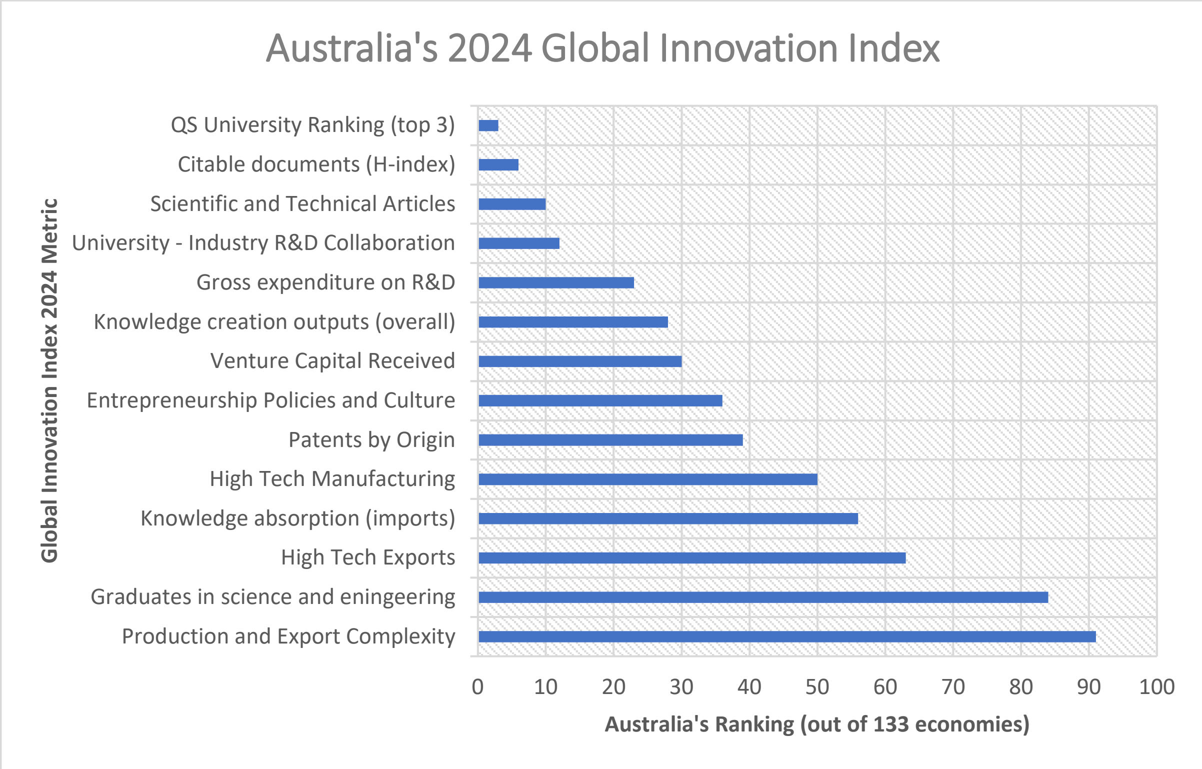

Figure 1. Global Innovation Index 2024 - Australia's R&D and Innovation Metrics [3]

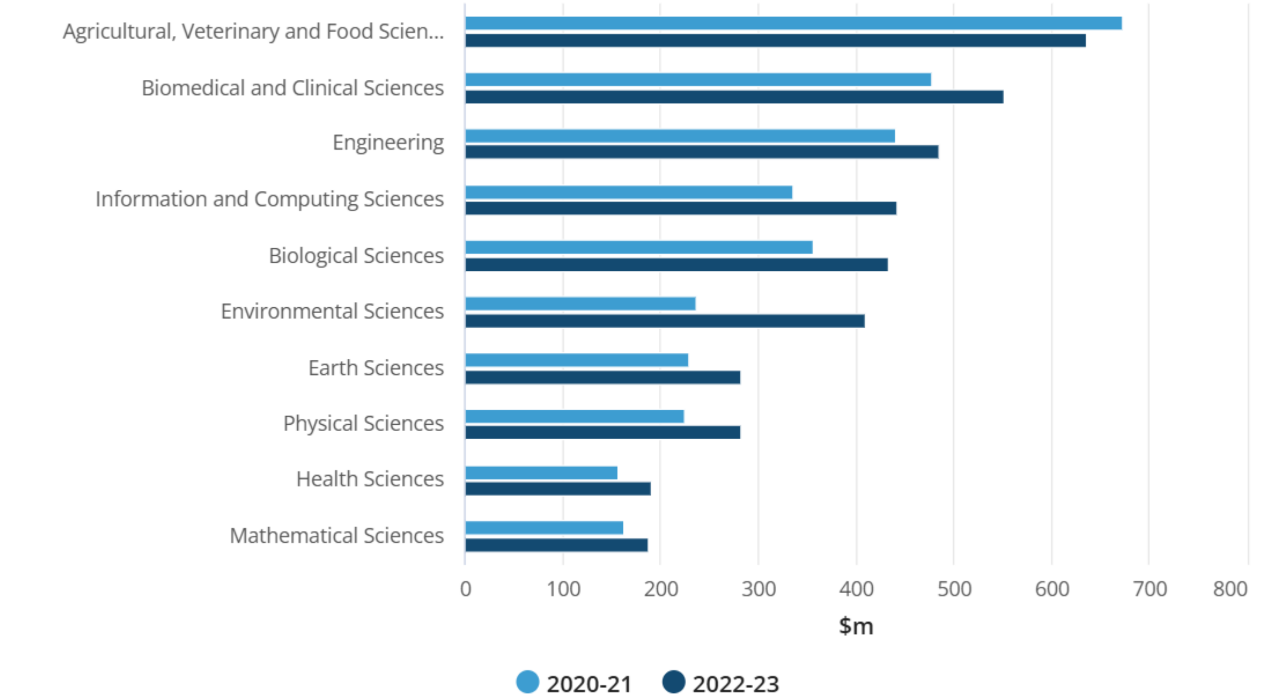

Figure 2.: Australian Government R&D investment by top 10 fields of Research [4]

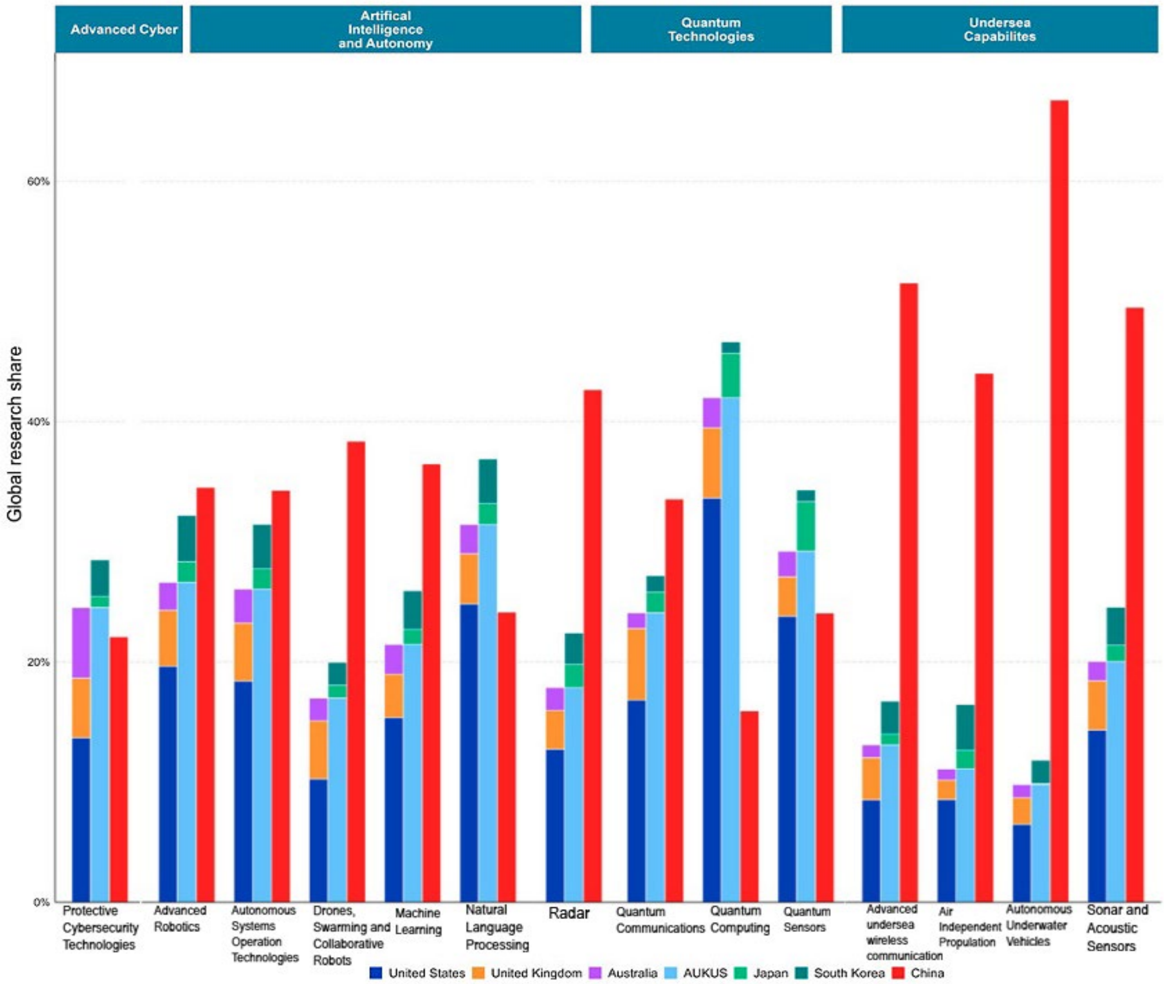

Figure 3.: Amended Research Share Graph of AUKUS Related Technologies (ASPI Report p.12, with non-marine science related technologies removed) [11]

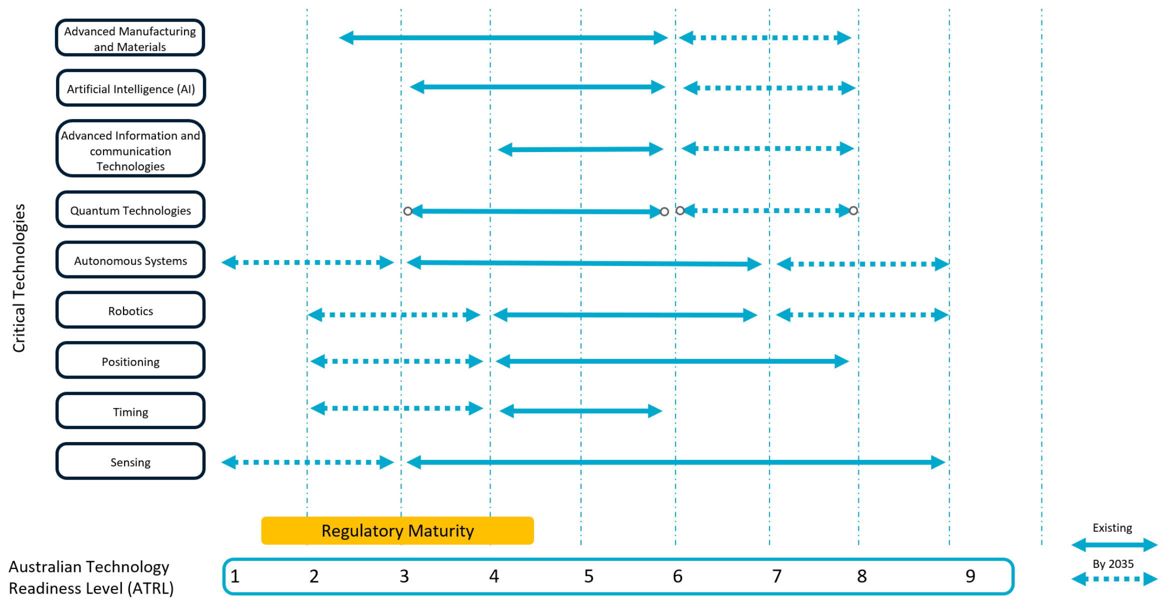

Figure 4. Australian Technology readiness level for select critical marine technologies

Infrastructure:	Monolithic -> Distributed
Sensing:	Single-modal -> Multi-modal
Planning:	Deterministic -> Probabilistic
Data:	Raw data -> Data products
Operations:	Lead agency -> Consortia

Figure 5. Global trends in marine observing

NATIONAL MARINE SCIENCE COMMITTEE

Supporting Annex

Glossary of Terms

AAD	Australian Antarctic Division
AIMS	Australian Institute of Marine Science
AMC	Australian Maritime College
ARC	Australian Research Council
BOM	Bureau of Meteorology
CRC	Cooperative Research Centres
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DSTG	Defence Science and Technology Group
FRDC	Fisheries Research and Development Corporation
GBRMPA	Great Barrier Reef Marine Park Authority
GOOS	Global Ocean Observing System
IMOS	Integrated Matine Observing System
IOMRC	Indian Ocean Marine Research Centre
NCMT	**National Centre of Marine Technology**
NCRIS	National Collaborative Research Infrastructure Strategy
SARDI	South Australian Research and Development Institute
SICA	Subsea Innovation Cluster Australia
SIMS	Sydney Institute of Marine Science
STEM	Science, Technology, Engineering and Maths
TASDCRC	Trusted Autonomous Systems Defence Cooperative Research Centre
TDEP	Technology, Development, Engineering and Prototyping
QUT (Centre of Robotics)	Queensland University of Technology Centre of Robotics
Uni Sydney (ACFR)	University of Sydney Australian Centre for Field Robotics
UTAS	University of Tasmania
UWA	University of Western Australia
WOCE	World Ocean Circulation Experiment