Submission in response to the Department of Industry, Science and Resources' consultation on a proposed framework for the Australian Government's National Quantum Strategy

Thank you for the opportunity to provide feedback regarding the Department of Industry, Science and Resources' (the Department) consultation on a proposed framework for the Australian Government's National Quantum Strategy (the Strategy). The University of Technology Sydney (UTS) has appreciated the considered engagement led by Australia's Chief Scientist, Dr Cathy Foley AO, to co-design the Strategy with the academic community and we look forward to its finalisation.

UTS is the top–ranked young university in Australia. Our vision is to be a leading public university of technology recognised for our global impact. As a university of technology, it is our role to ensure our graduates shape the future professions and businesses that will be needed in Australia and overseas. Since our inception, an integral building block of our success has been our outward, global focus and ability to partner with industry. Our campus has no walls; it is deliberately designed to be porous and support connections, knowledge exchange and collaboration. This embodies our approach to engagement and permeates our teaching and research. Our student body is diverse, and we encourage our students and staff to look at the world from different perspectives.

It is worth highlighting that UTS is one of the eight Australian universities referenced in the consultation paper for being a globally recognised leader in quantum research (page 6). UTS has specialised capabilities and deep expertise in quantum for research (e.g. Centre for Quantum Software and Information), teaching and education (e.g. School of Computer Science, School of Mathematical and Physical Sciences) and policy advice (e.g. Human Technology Institute).

With specific reference to the proposed Strategy, UTS makes the following four recommendations:

1. Objective 1 should focus more on continuing strong investment in scientific and technical foundations given that quantum computers and other sophisticated quantum technologies are at least a decade away from deployment on a scale that would be widely profitable for industry during the life of the Strategy to 2030.
2. That government support the creation of a national Quantum Software and Theory Institute to support the overall objectives of the Strategy (specifically 1, 3 and 4).
3. That government should engage with the expertise offered by the UTS Human Technology Institute to establish good ethical and legal guardrails to stimulate appropriate growth and commercialisation in the quantum industry.
4. That government prioritise the initiatives detailed under Objective 4 to secure the talent pipeline for the quantum workforce.

UTS's rationale for these recommendations is detailed below in reference to the consultation questions.

Do the objectives align with the needs for a thriving Australian quantum industry? Have any objectives or supporting initiatives been missed?

UTS is broadly supportive of the proposed objectives, acknowledging that the successful translation of research in practice is an iterative, non-linear process that requires a degree of opportunism and organisational flexibility for creativity, happenstance and entrepreneurism. The various initiatives outlined in the Strategy are comprehensive. An approximate timeline for implementation and delivery would assist in understanding government's own priorities and resourcing.

There is, however, one point of contention with the objectives that UTS wishes to raise and that is the strong emphasis on technology and infrastructure at the expense of research and innovation. In our view quantum computers and other sophisticated quantum technologies are at least a decade away from deployment on a scale that would be widely profitable for industry. This means public policy should focus on continuing the strong investment in scientific and technical foundations during the relatively short lifespan of the Strategy to 2030. It is well known that Australia under-invests in research compared to other OECD countries and that higher education expenditure on research and development has steadily increased while business and government expenditure has declined (2022, Committee for Sydney, *High*

Achievers: a plan for unleashing the huge potential of Sydney's universities). Noting that the consultation paper acknowledges that Australia's quantum companies already attract a significant amount of venture capital relative to international competitors (page 6), UTS contents that market factors should continue to drive opportunities for investment in industry infrastructure and commercial activities over the next few years.

For context, Australian quantum software, computing, and communications theory researchers have led, or contributed to, many important fundamental and applied quantum technology breakthroughs over the last 30 years. Examples include:

- the foundations of quantum software development (including algorithms, programming languages, and complexity theory)
- developing the notion of quantum teleportation
- publishing blueprints for the major quantum computing technology platforms being developed today (architectures)
- pioneering advanced techniques in quantum error correction
- the most efficient quantum simulation algorithms known to date
- the theoretical foundations for demonstrating quantum supremacy
- developing several designs for quantum communication networks
- key components that are instrumental in quantum sensing technology
- inventing the foundational building blocks of silicon and optical-based quantum computing

Furthermore, Australian, and Australian-based, theory and software researchers have made the fundamental discoveries that underpin much of the commercial growth in quantum technologies we see today. Richard Jozsa's foundational work on quantum algorithms gave the first hint that quantum computers could dramatically outperform classical computers, and his research into teleportation and the foundations of quantum information systems are now used in almost every aspect of quantum technologies. Gerard Milburn's contributions to optical quantum computing and the research that followed were the catalyst behind PsiQuantum and Xanadu. Likewise, Bruce Kane's proposal for silicon-based qubits sparked the research that has led to the creation of the companies Silicon Quantum Computing, Diraq, Quantum Motion, not to mention Intel's efforts in quantum computing.

These discoveries were not made with the expectation that they could be commercialised within a short timeframe or that in fact, they were even commercialisable. These discoveries drew on ideas across multiple fields and leveraged the tools of mathematics, physics, and computer science to make progress through the global research ecosystem. It is typical that the breakthroughs that ultimately lead to commercial success are made years before the commercial opportunity arises. More bluntly, foundational research sparks ideas which are built upon later to generate commercial utility.

Recommendation: Objective 1 should focus more on continuing strong investment in scientific and technical foundations given that quantum computers and other sophisticated quantum technologies are at least a decade away from deployment on a scale that would be widely profitable for industry during the life of the Strategy to 2030.

From these proposed objectives, what should the priorities be? Which initiatives should be addressed first?

UTS advocates for the prioritisation of the initiatives that drive research, education and innovation. It is worth noting that from a state perspective, NSW is primed for growth with the four universities who founded the Sydney Quantum Academy delivering world-leading quantum research; world-class quantum technology and expertise; and supportive innovation infrastructure with the support of the NSW Government. Sydney is also home to rapidly growing quantum computing startups such as Silicon Quantum Computing, Diraq, and QCtrl whose value has been driven by the intellectual property and talent emerging from this ecosystem. In addition, multinational corporates see Sydney as a key destination for quantum computing research providing significant funding into this ecosystem. Microsoft has established a quantum computing research laboratory at the University of Sydney and Google is

funding a range of quantum software-focussed projects across UTS, Macquarie University, UNSW, and the University of Sydney.

Listed below, in order of preference, is UTS's recommendations for which objectives of the Strategy to prioritise i.e. Objective 1, followed by Objectives 7, 4 then 3.

1. **Objective 1: Create a thriving environment for development, commercialisation and use of quantum technologies**

   UTS contends that the most impactful government-led initiative would be to create a national Quantum Software and Theory Institute (QSTI) that incorporates fundamental research projects, facilitates the creation of software infrastructure in support of Australian industry, and equips the workforce of tomorrow. Such an institute would ensure a continuous supply of new intellectual property into the Australian ecosystem, provide long-term research support, attract internationally competitive talent, and provide both the scientific foundations and talent for the continued growth of the sector. A well-funded national institute would provide the necessary support for ambitious research projects and ensure a steady growth of the foundational research to underpin commercialisation (Objective 3). The institute would also have a strong educational component, attracting international talent and training the next generation of quantum scientists and engineers (Objective 4). Open collaboration with industry partners and academia across a breadth of fields, and the nation, is essential and would be at the core of this national institute, with a clear objective to assist industry partners with taking the first steps towards product development and software infrastructure.

   It is important to note that the proposed QSTI would be able to leverage the newly formed Australian Quantum Software Network (www.quantumsoftware.org.au) which is aimed at returning Australia to the forefront of quantum software research and development. The AQSN is designed to accelerate the theoretical and software foundations for quantum computing by building partnerships, both domestically and internationally, and was launched with over 100 members across 30 academic groups at nine universities and two Australian-based quantum software startups. This network represents the world's most extensive collection of quantum software and information theory expertise:

   - University of Technology Sydney
   - Royal Melbourne Institute of Technology
   - University of Sydney
   - University of Western Australia
   - Macquarie University
   - University of Melbourne
   - Griffith University
   - University of Queensland
   - University of New South Wales
   - Monash University
   - CSIRO
   - Australia's first Venture Capital-backed Quantum Start-up, Q-CTRL Pty Ltd
   - Sydney-based quantum education startup, Eigensystems Pty Ltd.

   The AQSN has also teamed up with six initial partners to foster collaborations and partnerships between quantum hardware and software:
   - Google Quantum AI
   - Okinawan Institute of Science and Technology (OIST) in Japan
   - Aalto University, Finland
   - Australian venture capital-based quantum hardware companies Silicon Quantum Computing, Quantum Brilliance and Diraq Pty Ltd

Recommendation 2: that government support the creation of a national Quantum Software and Theory Institute to support the overall objectives of the Strategy (specifically 1, 3 and 4).

2. **Objective 7: Build trust, ensure inclusivity and balance national interests**

   UTS is committed to the lawful and ethical use of technology and data. This commitment is embodied in the mission of UTS's Human Technology Institute (HTI; https://www.uts.edu.au/human-technology-institute) which is focussed on imbuing technology with human values by promoting a human-centred approach in a way that responds to the needs of our community, and ultimately, enhances fairness, accuracy and accountability.

   By way of example, on 27 September 2022 HTI published a world-leading report outlining a model law for facial recognition. This report responds to growing calls for reform from leading voices in civil society, the private sector, government, and academic experts. The proposed law is designed to protect against harmful uses of facial recognition, while also fostering innovation for public benefit.

   The social impact of quantum technologies is potentially similar to technologies like AI and big data. Technology, poorly designed and poorly implemented, can replicate and entrench existing inequalities. Accordingly, UTS urges government to take a strong leadership approach to the lawful and ethical use of quantum technology.

Recommendation 3: that government engage with the expertise offered by the UTS Human Technology Institute to establish good ethical and legal guardrails to stimulate appropriate growth and commercialisation in the quantum industry.

3. **Objective 4: Drive skilled workforce growth to scale industry and make Australia the top destination for quantum technology talent**

   For efficiency, the importance of Objective 4 is discussed in relation to key risks that would impact these objectives being met.

4. **Objective 3: Enhance Australia's global leadership in quantum research**

   Quantum computing in Australia has developed on the basis of Australian Research Council competitive funding programs, including the ARC Centre of Excellence programs (particularly the ARC Centres of Excellence for Quantum Computation and Communication Technology and Transformative Meta-Optical Systems), Discovery Programs and Linkage Programs which have provided continuity and support for Chief Investigators and collaborators. While the Centres of Excellence have allowed many teams to explore long-term research challenges and train early-career researchers, the funding failed to grow with the community and many mid-career researchers received limited opportunities to consolidate their research programs.

   To overcome this barrier, we again draw government's attention to the recommendation to create a national Quantum Software and Theory Institute. The Institute should be funded by government and industry and would help ensure Australian leadership and continuity for the quantum theory and software research community. By integrating foundational research and education together with industry-facing prototyping and development in a single entity we believe that foundational research could be supported by industry funding. Any such institute would need to be focussed from a location with a large fraction of both the research community and quantum technology industry. However, we would expect that there is no barrier to provide funding nationwide, and one of its main purposes would be to bring scientists together overcoming geographic concerns.

What are the key risks that would impact these objectives being met?

At the present time, the greatest risk that would impact these objectives is a failure to achieving Objective 4 *Drive skilled workforce growth to scale industry and make Australia the top destination for quantum technology talent.*

As discussed in the consultation paper, the talent pipeline is critically important to Australia's quantum future and Australian researchers are being successfully recruited to work for competitors overseas, taking their intellectual property and talent with them. The absence of a skilled workforce with critical mass will greatly undermine the Strategy and its aspirations to ensure Australia will become a world-leading quantum ecosystem.

To appreciate the challenge faced by Objective 4, it is important to understand that the quantum research workforce is multilayered, diverse, and highly specialised (refer to Figure 1: the "Quantum Software and Theory Stack"). For example, UTS's Centre for Quantum Software and Information engages in quantum software and theory research that broadly covers the entire "quantum technology stack" integrating a diverse range of skills from quantum mechanics, information theory, error correction, architecture, algorithms, software engineering and application design.

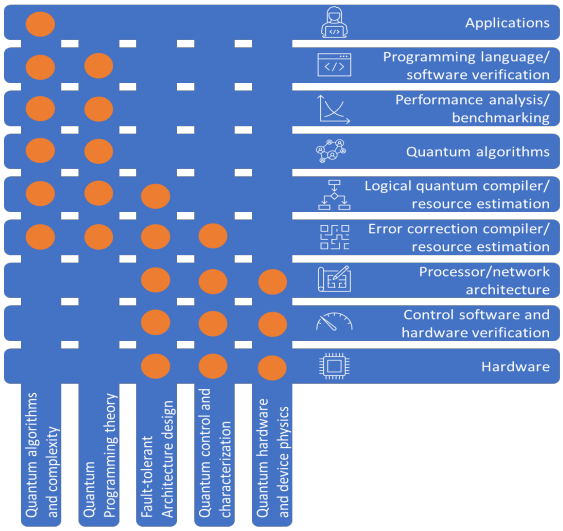

Figure 1: The Quantum Software and Theory Stack, with technologies represented as horizontals and fields of research represented as verticals (quantumsoftware.org.au)

Australia will continue to require expertise across this broad range of disciplines if the value of quantum technologies is to be captured here. Importantly, research progress and training in these fields of research are almost entirely dependent on highly skilled talent. Without clear opportunities to undertake fundamental, university-based, research Australia will struggle to retain the talent that is required to train the workforce responsible for the design and deployment of future quantum systems and devices.

UTS is a public university of technology which informs our approach to teaching and research. Accordingly, UTS has established various programs and initiatives to encourage Australians to consider a future career in STEM and computer science. In our view, the Wanago Program and IDeA (scheduled to commence in 2023) are two models which merit consideration under the Strategy:

- The Wanago Program (https://www.uts.edu.au/about/faculty-engineering-and-information-technology/what-we-do/wanago-program) was launched in 2019 and delivers NSW STEM HSC subjects to high-school students in years 11 and 12. The Program enables students from schools, where the numbers are too small to provide STEM classes, to participate in a 'pooled' class at UTS's state of the art facilities and in community settings. Wanago was initially a UTS social justice initiative and seeks to assist students typically underrepresented in STEM industries, such as female students, and students from low SES backgrounds. Wanago provides a two-pronged approach to address students' critical need to access STEM subjects. The first is to attend to the immediate need of providing STEM subjects to students who are unable to access subjects at their school. The second is to address the urgent lack of STEM teachers in NSW schools. The Program connects students, teachers and their schools to UTS academics, students and industry

partners to inspire high school students to undertake STEM tertiary study, and help shape the future workforce. Importantly, the classes are composed with a balanced female/male ratio.

- IDeA (Industry Degree Academy) (https://www.uts.edu.au/study/information-technology/courses/undergraduate-it-courses/bachelor-computing-science-industry-degree-academy-idea) is a new cadetship aimed at school leavers which is designed to develop the next generation of tech professionals. Participants graduate with a Bachelor of Computing Science as well as two years of industry experience. The program is co-designed with industry partners[1], meaning students graduate with the skills and experience that employers are looking for. More information about the program can be found here:

It is also worth drawing attention to the Sydney Quantum Academy (SQA: https://sydneyquantum.org) of which UTS is a founder and key partner together with Macquarie University, UNSW Sydney and the University of Sydney. The SQA was developed specifically to build on the strength of NSW's quantum ecosystem to deliver a suite of educational programs designed to create a new workforce of quantum technology leaders, specialists, researchers and entrepreneurs:

- PhD Programs
- Undergraduate Programs
- School Programs
- Internships

One of the most important functions of the SQA has been to enhance cross disciplinary, and cross-institutional learning especially for postgraduate students. Students are exposed to a broader set of pathways into quantum technology than would have been possible before the creation of the SQA. This is providing more opportunity for collaboration, but also better equipping our graduates for a larger range of opportunities in the quantum ecosystem.

In summary, the demand for talent in the quantum workforce is evolving, and it is to be expected that the traditional pathways into these fields will also evolve. UTS has focussed on increasing the breadth of pathways that will allow students to embark on a career in quantum technologies, with degree programs offering cross faculty and discipline study that will broaden students' opportunities. The future workforce in quantum technologies will require much more quantum literacy across many more occupations. Ensuring that universities are equipped to provide this education will be essential for the continued growth of the quantum sector.

Recommendation 4: that government prioritise the initiatives detailed under Objective 4 to secure the talent pipeline for the quantum workforce.

Other opportunities and considerations

A final recommendation for the Department is consideration of utility benchmarking and the future needs of Australian industry. Academia is often asked: "What impact will quantum technologies have on my life and/or my business?" At this point, we know that quantum computing and technology presents a tremendous opportunity for industry, but it will not uniformly benefit all industries at the same time. Discovering and evaluating applications for industry-relevant problems is already a focus of UTS's Centre for Quantum Software and Information (QSI). This practice, known as utility benchmarking, involves a close collaboration between industry experts with domain knowledge and quantum theory researchers. QSI foresees that evaluating the value proposition of quantum approaches will be essential as the development of these technologies accelerates. Accurately predicting the feasibility, scale, cost, and timeframe for deployment of quantum technologies will allow Australian businesses to establish a timeline for adopting quantum technologies, staying ahead of the competition but avoiding premature hype.

[1] Rolfe, M (9 September 2022) *How to get paid six figures to go to uni* Daily Telegraph accessed 21 September 2022.

Quantum algorithms are currently benchmarked manually by a few experts over several months per application. We believe that this practice can be significantly accelerated with software tools to model error correction, represent modern algorithmic techniques, and compile into low-level instruction sets. Developing such tools will not only assist in commercialisation of quantum computing for traditional industry, but also informs the research underlying the design of new processors, error-correcting codes, and algorithms all of which will be essential ingredients for Australian quantum technology companies.

To illustrate this point, QSI provides the following case study for consideration:

DARPA: Quantum Benchmarking
QSI is participating in the US Defense Advanced Research Projects Agencies *Quantum Benchmarking* program which began in 2022. As part of the multi-million-dollar partnership, QSI at UTS is working with some of the world's leading corporations and quantum startups. Primary project partners include HRL Laboratories, Zapata Computing, and Rigetti Inc. who are collectively developing new technologies and tools for the assessment and benchmarking of quantum computing algorithms and applications at scale. One side of this program is focussed on assessing the utility of high-value algorithms used by domain experts at companies like Boeing and General Motors, who are also partners in our projects. The other side of this program is developing the "Bench-Q" software suite with Zapata Computing, the University of Southern California, the University of Texas at Dallas and Aalto University, Finland for the purpose utility estimation and to enhance the processor design and experimentation of quantum hardware companies IonQ and Rigetti Inc.

Conclusion

The opportunity in quantum software and theory development represents a critical element of Australia's leadership in quantum computing and technology. Accordingly, we encourage government to capitalise upon this opportunity and make it a priority for ongoing investment. Importantly, theory research is almost entirely dependent on talent, and Australia must compete in order to attract and retain that talent. A commitment to attracting and retaining talent is essential for successfully implementing the recommendations put forward in this submission.

UTS appreciates the opportunity to contribute and would welcome future engagement over the Strategy and implementation of the various initiatives. Please do not hesitate to contact Amy Persson, Head of Government Affairs and External Engagement (amy.persson@uts.edu.au) should you wish to discuss this submission further.