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AusQuantech Briefing Paper

Background

Australia recognised the potential and the promise of quantum technology ahead of most of the rest of the world. Over several decades we have invested hundreds of millions of dollars in fundamental and applied research with spectacular results from our universities and institutes. Today Australia is a global leader in quantum technology research.
So far, Australia has not matched this with the investment, entrepreneurship, and development of a commercial culture required to exploit our quantum technology research and realise returns on our research investments. Despite our world-leading position we do not have a significant quantum technology industry sector (QuanTech Industry / Sector).

Purpose

This paper proposes that the Australian community of quantum technology researchers, funders, users, vendors, suppliers, trainers, entrepreneurs, investors, businesses, and supporters should form an industry group – The Australian Quantum Technology Forum: AusQuantech.
AusQuantech's purpose will be to unify the sector, find and build consensus among the stakeholders, and to motivate, advocate for, and facilitate the development of a substantial quantum technology sector in Australia.
AusQuantech will speak with one voice on topics relevant to our mission and our members. We will seek to influence policy debates and act as an organising focus to promote the interests of Australia's QuanTech sector.

This paper

To establish AusQuantech we must come together as a group of interested and motivated stakeholders who will build our industry. We must agree on the vision for an Australian QuanTech Sector and then take steps to make this come about.
This paper sets out the basic founding assumptions that have so far driven this process, and then poses a series of basic questions and proposed answers that AusQuantech will need to address as it forms and in the beginning stages of setting the course for our future QuanTech Sector.

What can you do?

1. **Read this paper.** Think about its contents, implications, and what future you want to see for Australia's QuanTech Sector.

2. **Spread the message.** Forward this paper to other stakeholders you think would be willing to help build our industry along with your request that they help out.

3. **Participate!** Email ausquantech@gmail.com and give us your thoughts on this paper. Tell us that you want to participate. Make suggestions about how we should develop our industry in Australia. Visit www.ausquantech.org and sign up to our mailing list and help make this happen.

Founding assumptions

1. **Australia should have a commercial quantum technology industry (QuanTech Industry / Sector) to complement and commercialise our ongoing research and provide a return on the substantial public investments we make in the field.**

    a. Our QuanTech Sector should be broad based and include consideration of all uses of quantum phenomena and those incidental developments which occur while investigating quantum phenomena.

    b. The QuanTech Sector naturally divides into R&D segments based on application, with some commercial use cases drawing on multiple segments:

        i. ***Quantum computing hardware*** i.e. build a quantum computer.
        E.g. Silicon, NV centres, superconducting, ion.

        ii. ***Quantum computing software*** i.e. do something useful with a quantum computer.
        E.g. quantum algorithms, quantum simulations, benchmarking, verification, error correction, control, encoding/readout.

        iii. ***Quantum sensing*** i.e. measure something interesting with a quantum system.
        E.g. Magnetic, electric, gravitational, mechanical force, rotation, motion, photons.

        iv. ***Quantum communications*** i.e. distribute information, either classical or quantum, securely with quantum phenomena.
        E.g. cryptography, secure messaging, trust and verification, quantum resource distribution, secure verified voting.

        v. ***Quantum resources*** i.e. make the quantum building blocks needed by other segments.
        E.g. single photons, entangled particles, random numbers, entropy, atomic clocks.

        vi. ***Classical interface***, i.e. the classical equipment required to interact with quantum phenomena.
        E.g. lasers, detectors, oscillators & clocks, high speed electronics, superconducting devices, optics, test equipment.

        vii. ***Quantum inspired***, i.e. other inventions made while pursuing quantum research and development.
        E.g. spectroscopy, instrumentation, optical or electronic devices, calibration systems.

2. **A commercial QuanTech Industry will:**

    a. Build on the recent decades of academic research investment in Australia and overseas, e.g. by developing new inventions locally rather than overseas.

b. Provide economic and social benefits to Australia, e.g. by manufacturing and selling quantum technologies developed locally.

c. Provide career pathways for locally trained quantum technology graduates and entrepreneurs, e.g. by supporting a career pathway for graduates.

d. Export quantum technology components, devices, training, and knowhow while retaining local competence and capacity, e.g. by selling software, services, packaged parts, or entire subsystems.

e. Service sensitive defence, national security, and strategic needs from local capabilities, e.g. by keeping key innovations and expertise onshore and available for sovereign use.

f. Provide quantum technology advantages to other local industry and allow for onshore innovation in economically important sectors, e.g. by collaborating with other sectors to find new opportunities or efficiencies using quantum technologies.

3. **Establishing a viable QuanTech Industry will require the development of local manufacturing capability in Australia.**

   a. All end-use applications of quantum technology require some physical embodiment to execute the technology in an economically or strategically valuable way.

   b. We capture the most value and best protect our substantial research investments by holding intellectual property (IP) in Australia while developing, manufacturing, and selling the key components and systems.

   c. A purely software based QuanTech Industry will not deliver on all the opportunities our significant research investments have provided.

   d. A purely consulting- and/or training- based QuanTech Industry will not keep IP and capability in Australia, instead we will be exporting our hard-won research leadership in the field.

   e. Different aspects of commercial quantum technologies will require different manufacturing, supply chain, logistics, and supporting infrastructure.

   f. Production-grade manufactured quantum technology devices cannot be delivered consistently and economically from research-grade facilities. Customers require security or supply and quality which cannot be delivered by research facilities.

4. **It is neither practical nor economically viable to establish all the requirements for every quantum technology segment in one location. Instead localised hubs should be established where segments with shared requirements can share the costs across multiple markets, businesses, and products.**

a. Infrastructure and facilities that would be shared by multiple commercial QuanTech Sector users should be in geographic proximity (QuanTech Commercial Hubs) to leverage capabilities, logistics, staffing, and cost savings.

b. Many support services required for operating and maintaining the facilities (e.g. local precision machine shops, service technicians, HVAC, and electrical technicians, etc) do not warrant employing dedicated staff, so contracting local businesses will be used. The activities require training and understanding the special requirements associated with the facilities. It is more efficient to have these localised and shared rather than establish fresh contractors for every project or business.

5. **A commercial QuanTech Industry in Australia will not be able to service all potentially commercial quantum technology products. Choices will be made by strategic forward planning, or less efficiently forced by natural selection.**

    a. Just as the Australian research community is not undertaking programs of work in all possible aspects of quantum science, it is unlikely that an economy and population the size of Australia's will be capable of supporting the development of a viable industry for all quantum technology applications.

6. **For planning purposes, we assume quantum technologies will become commercially relevant to Australia in the following timeframes:**

    Now → : Niche sensing, quantum resources, communications, and control engineering.
    → 5 yrs.: Packaged discrete sensing components, early simulation services, early communications and cryptography applications.
    → 10 yrs.: Integrated sensors, quantum simulations, enabled communications and cryptography, non-universal quantum computing, noisy intermediate scale quantum computing.
    → 20 yrs.: Centralised universal quantum computing.
    → 50 yrs.: Distributed quantum computing.

Basic questions & proposed answers:

1. **What do we want for Australia?**

    a. A long-term viable QuanTech Industry based on local research, product development, and manufacturing.

    b. An export driven QuanTech Industry which on ~20 years' timescale contributes 1-2% GDP to the economy and provides additional non-economic social returns in proportion.

    c. A local quantum technology manufacturing industry focussed on high value components and subsystems, using Australian R&D, IP, and workforce.

    d. Ongoing support for academic and commercial research in quantum technology to provide workforce training, new innovations, and technologies, and maintain our production of high-quality basic science.

    e. A net increase in quantum technology industrial R&D and basic research, to be funded from commercial sources, while maintaining or growing the current government basic research investments and funding mechanisms in quantum science and technology.

    f. A QuanTech Industry which is integrated and collaborates with the academic research community, providing research funding, CRCs, collaborations, placements, and internships, etc. Build linkages between research and industry generating an increase in total funding for quantum research.

    g. Proven capability and reputation for excellence in developing a quantum workforce; including staff with technical, academic, and business leadership skills.

2. **Should we have native manufacturing?**
   If so, to what extent? Niche, general, mass production, component, and subsystem, etc

    a. Local manufacturing for at least some key QuanTech Sector segments is required to keep IP and people in Australia, and to deliver the significant economic benefits quantum technology will bring.

    b. Local manufacturing, even at pilot-scale, under production-grade conditions allows for a much more rapid prototyping cycle than using overseas facilities. Moreover, local manufacturing brings production and process engineering considerations into the development loop much earlier than otherwise possible, further speeding the eventual delivery of production devices.

    c. Local quantum technology-based manufacturing will be small to mid-scale production facilities, probably with shared or fee-for-service style infrastructure to service them. Because of the need to most efficiently utilise shared infrastructure this manufacturing will cluster geographically into hubs where common requirements can be met in a cost-effective manner even though no single manufacturer has sufficient scale. Examples of shared

infrastructure include semiconductor fabrication, device packaging, testing and metrology, lifetime and failure analysis, electronics engineering and layout.

d. It is unlikely that Australia will locally produce significant quantities of finished quantum technology products for retail sale – compared to international options we have high labour costs and relatively high ancillary costs to manufacture. Production of commodity items and final assembly will almost certainly occur in a global supply chain.

e. We will not manufacture in all segments, just those where we have significant advantages which can be incorporated into high-value devices for export and subsequent integration into end products.

f. Australia has recently had some notable successes with this model of government encouraging high-tech industry and diversifying the complexity of our export base. An example is the Queensland government and aerospace: Queensland is now home to 31% of Australian aerospace, with over 300 enterprises employing 4200 people, >50% of industry revenue is from exports, and in 2015-16 aerospace contributed $565m to the Queensland economy.
(https://www.statedevelopment.qld.gov.au/industry/priority-industries/aerospace.html)

g. An example of on-shore manufacturing of high-value systems for export into a global supply chain is Cochlear.

h. Further value-add or combining with commodity components can be achieved by the Australian company by 'virtual factories' or 'fabless' models for high volume manufacturing to economic scales by leveraging access to global supply chain and logistics. This allows an Australian maker of a high-value quantum component to contract overseas capability to further assemble the Australian component into a more valuable subsystem or product for on-sale by the Australian business without having to develop the full fabrication and supply chain required.
Examples from semiconductor include Qualcomm, AMD, Broadcom, Nvidia, Marvell, Xilinx, Realtek, …

i. In summary, our options include:

    i. Make the quantum device in Australia and sell.

    ii. Make and package the quantum device in Australia and sell.

    iii. Make and package the quantum device, and further elaborate into a subsystem in Australia and sell.

    iv. Undertake key high-value manufacturing in Australia and ship to contract manufacturer for completion and sell.

    v. Complete finished product in Australia.

3. **Which segments of our QuanTech Sector require immediate action to avoid missing the opportunity? And which segments need long-term planning to be ready when they mature?**

    a. Identify & prioritise near-term opportunities backed by existing market pull and readiness of a commercial offering. A commercial offering does not mean a finished product, but something which has a customer base and we can deliver on from local resources and capabilities, e.g. defence spending and special projects.

    b. Quantum sensing, quantum computing software, and quantum communications are segments where immediate opportunities and capability exist. All these can deliver outcomes or devices which can be built locally, possibly via a fabless model and would not require each business to invest in large scale manufacturing infrastructure. Ancillary capabilities could be provided at first via the university sector, but ongoing, reliable, well maintained, and production grade infrastructure will be required very quickly as these opportunities scale.

    c. Quantum inspired technologies are less predictable as to manufacturing requirements and will be treated similarly to existing commercialisation and production pathways for engineering and physical sciences.

    d. Quantum computing hardware is at such an early stage of development that there is presently no way to be certain of the manufacturing requirements. This segment is extremely important and Australia's leading research places us in a prime position to be ready to act once the hardware design and production processes are established. For now, there is no commercial driver to develop a manufacturing hub or infrastructure for this segment.

4. **Are the assumed timescales appropriate?**

    a. Developing manufacturing competence from a standing start at a brownfield site for mass production of commercial products could take 3 years:

        i. Acquire site & fit out

        ii. Hire initial staff – management and technical leads

        iii. Specify and purchase production and metrology tools

        iv. Site facilitisation and tool qualification / factory acceptance

        v. Hire tool owners / engineers

        vi. Receive and install tools, site acceptance testing

        vii. Characterisation and process development

        viii. First production pilot and testing

        ix. Production process scale up testing

x. Ramp to high volume manufacturing

b. Once a manufacturing site is established the time from process development to pilot should be 6-9 months. One advantage of the share infrastructure hub model is that each new product does not require the full production buildout cycle – saving money and time.

c. Currently Australia's quantum technology research delivers technologies which are far from products and usually lack a dedicated proponent to carry forward the commercialisation. These require product management, market investigation, R&D, product engineering, etc to be converted into saleable products. This development cycle and design in will take ~2 years to have a product ready for manufacture.

5. What is the place of academic research in Australia's commercial QuanTech Industry?

a. Train the high-skill workforce required for basic research, manufacturing hubs, production R&D, engineering, technical management, and commercial management, i.e. Train the employees and managers of the startups, businesses, hubs, and large companies that comprise the Australian QuanTech Sector.

b. Generate new fundamental research, discoveries, and inventions which can be translated to the QuanTech Industry for commercialisation. This requires a research translation function embedded in the research centres and/or provided by the universities.

c. Provide a steady flow of startups, technical founders, and research managers with the ability to step in and out of the academic and commercial spheres and so grow the industry as a whole, i.e. generate the new businesses along with the motivated people to drive them, i.e. Entrepreneurs, founders, and visionaries to build the businesses that form the foundation of Australia's QuanTech Industry.

d. Act as a repository of expertise that connects actively with industry providing for a two-way dialogue on problems that are seeking solutions and new innovations that could solve a problem.

e. Be a friendly early adopter customer base for local QuanTech Sector businesses, suppliers, and ecosystem by purchasing products and providing feedback.

f. Service requests for contract research for the local industry.

g. Continue producing world leading research outputs which maintain Australia's international reputation as a source of high-quality quantum science. Long term research and fundamental innovations will come from academia, whereas short term development will come from industry.

6. **What will be the relationship between industry-led research and academic research?**

    a. Academic research will have a long-term approach and is a public good in its own right, industrial research will be necessarily narrower in scope and short term in requirement to serve some industrial, or commercial need.

    b. Academic research will continue more-or-less as it is, with a focus on basic science and fundamental understanding of quantum phenomena. There will be research translation embedded in the academic environment to facilitate the conversion of research outcomes into technologies and then prepare these technologies for commercialisation. Academic research will be informed by input from industry, but the research goals should be curiosity driven and not reliant on commercial applications.

    c. Industrial research in quantum technology will focus on development of technologies into products and then integration of these into finished goods. Some industrial research will be focussed on solving problems of commercial importance either using their own resources or by managing a collaboration with academic researchers.

    d. Dialogue between academic and industrial research will provide fertile opportunities for both. Sharing of problems and solutions will also facilitate advances in basic science and more applied engineering disciplines.

    e. The presence of a thriving local QuanTech Industry will provide the academic research sector with a career path for its graduates, a source of research funds, a pathway for commercialisation, and an ecosystem in which to flourish.

7. **What is the geographic model for a QuanTech Industry in Australia?**

    a. Hub model: shared infrastructure for manufacturing, equipment, facilities, etc. Hub has its own management and technical staff to operate as a service provider/vendor for businesses and researchers; Access is on a fee-for-service basis. Hubs will be operated like production facilities, not research laboratories.

    b. Each hub has a QuanTech Sector segment focus, e.g. sensors, or communications. The hub establishes manufacturing competence for its domain to service the quantum technology for that segment.

    c. Hub domain is set by the preponderance of expertise and academic research in the region, and with regard to existing commercial activities.

    d. Hubs are open to anyone in Australia to participate and use, but the infrastructure is clustered and physically located together – important to reach critical mass. Centres may be in in Brisbane, Sydney, Melbourne, and Adelaide.

e. Hubs could be near or on main university sites. However, it is important that these hubs maintain independence and accessibility. They need to be and be seen to be independent and accessible.

8. Should the industry be seeded by building infrastructure and waiting/expecting business to accrete or let it grow organically? How could either be achieved?

a. Organic growth won't work because there is no local economic driver to overcome the pull from more established quantum technology commercialisation centres overseas, i.e. there is no base from which to grow organically, and pressure to make fast progress with investors' funds will force any emerging commercial base to relocate fairly early.

b. Government support is required to establish at least two hubs and build out infrastructure and fund OpEx until an ecosystem develops over the following 5-7yrs. Potential first hubs could be:
Quantum Sensor Manufacturing hub
Hub for Quantum Communications and Cryptography
Hub for Quantum Device Packaging and Subsystems
Hub for Quantum Control (mostly software and high speed electronics)

9. Do we develop a wholly native industry, import existing commercial organisations to set up here, or some combination? How will this be managed?

a. Incentivise the few local quantum technology commercial entities in Australia to relocate to a suitable hub, or at least make use of the hub facilities.

b. Provide incentivised (incubator style?) facilities for startups and SMEs to locate at and use hubs.

c. Bring in some existing large corporates to establish R&D centres at the hubs. Important that the focus of the import be aligned with the hub and national interests

d. A useful example to consider is the UK where hubs of the type described here have been operating for some years. In that country they have large and medium enterprises attracted to locate in proximity to hubs based on access to other businesses. Similarly, these hubs are close to concentrations of academic and translational expertise which is leading to the commercialisation of technologies and new startups being founded.

10. How do we bring home existing talent? And keep emerging talent in Australia?

a. Provide enough skilled jobs at appropriate seniority and pay.

b. Provide same or better commercial opportunities as those offered by our competitors.

c. Fix systematic issues with:

   i. Technology translation.

   ii. Management of IP generated by publicly funded research.

   iii. Investment models for Australian startups.

   iv. Career impacts for staff moving between academic and commercial entities and back.

   v. Lack of manufacturing capability suited to quantum technology focussed manufacturing.

d. More fluid movement in and out of academic / government (CSIRO/Defence) research. Ideally joint research/commercial roles are encouraged and rewarded. (Are there superannuation / long-service / redundancy issues?).

e. An encouraging recent development is DST Group hiring Quantum Technologists from academia to be full-time employees and continue to be based at their Universities working on DST Group funded projects.

11. What are the roles of the industry association AusQuanTech?

f. To speak with one voice for the entire Australian quantum technology industry.

    i. A unified voice from the commercial and research stakeholders when creating and dealing with matters of policy

    ii. A consolidated view on quantum technology across research, commercial, and end user; with global perspectives and local expertise.

g. To promote and advocate for quantum technology in Australia, and for Australia's QuanTech Industry globally.

    i. Programs to grow the industry and to expand the customer base.

    ii. Develop the workforce.

    iii. Standards for manufacturing, product specification, lifetime testing, training and certifications, etc.

    iv. Attract inbound commercial opportunities / partners / vendors / customers.

    v. Advise on supply chain and offshore production.

h. To provide informed and expert advice on matters of trade and policy as they intersect with quantum technology and the QuanTech Sector in Australia and globally.

    i. Provide early visibility into upcoming issues and matters of concern at local and global levels to government.

    ii. Contribute to defence and national security planning.

    iii. Advise on future economic and technological scenarios.

i. To assist Australian state and federal government bodies to set national and state priorities for quantum technology.

    i. Assist with the establishment of a QuanTech Industry in Australia.

    ii. Provide an on-ramp for government industry development and innovation assistance in Australia's QuanTech Industry.

j. To promote and facilitate links between industry and academia.