National Quantum Computing Centre

Annual Report 2021

© Hawkins\Brown. Artist's impression of the NQCC's new facility on the Harwell Campus, due for completion mid 2023.

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Foreword

Dr Michael Cuthbert
Director, NQCC

Despite the challenges brought about by the pandemic over the past 18 months, the National Quantum Computing Centre (NQCC) was successfully launched into the UK quantum technology eco-system a year ago. Throughout the past year we have rolled out our programme across six key themes.

Development

Firstly, we progressed the business case for the centre through government gaining the necessary approvals for our plans, budgets and delivery mechanisms. Secondly, we progressed the facility construction from concept design, through architectural detailing, planning consent, site clearance, enabling works and breaking-ground. Thirdly, we developed our technology roadmap and identified early work packages that have been commissioned in a way that engages with the academic and start-up communities, supporting and accelerating the development of quantum computing (QC) in the UK. Throughout these three activities we have engaged with technical specialists across the UK, who have provided valued insight and advice, helping to shape our operating model, facility design and technology requirements. Furthermore, this engagement has helped the NQCC gain credibility across our stakeholder network. I am incredibly grateful for the tremendous support we have had from our subject matter expert cohort.

Deployment

The remaining 3 key areas of activity have been in engagement, outreach and recruitment. A priority for the NQCC is not only to scale our technology platforms to provide useful QC resources but also to scale the adoption of the technology through the creation of a vibrant user community. A quantum ready economy is one that can take advantage of the opportunities presented by quantum technologies and in particular QC. Building on this effort will be a key focus in the coming year creating access to commercial QC resources, providing technical and applications support, as well as holding deep dive workshops to identify sector-specific use cases.. Throughout the year we have supported numerous webinars, workshops and panel sessions. It has been wonderful to see these outreach opportunities start to migrate back to in-person events with the National Quantum Showcase eagerly awaited. Finally, we have been building up our team throughout the year and I am delighted to see our organisation developing and look forward to welcoming more new members to join our endeavour in the year ahead.

On behalf of the leadership team, I welcome this first annual report as confirmation of the progress made to establish the NQCC and extend our thanks to our Programme Delivery Board and Programme Advisory Committee for their insight, encouragement and support in what has been an extraordinary year.

UKRI National Quantum Computing Centre

Contents

Executive Summary

Quantum computing has the potential to unlock unprecedented parallel processing, creating a step change in computing power. By harnessing and exploiting this capability the UK has an ambition to become the world's first quantum ready nation. To achieve this a renewed effort is required leveraging the £1bn, 10 year investment already committed into quantum technologies since 2014.

Our effort is part of a global race with significant international investment in hardware, software and skills. Recruiting and retaining top talent is of key importance. The long term impact of quantum computing on society and the economy is potentially huge with a projected global market of $450-850 billion annually over the next 15-30 years.

Building on the investments made in enabling science, a new National Quantum Computing Centre (NQCC) is being established on the Harwell Campus with an initial investment of £93m over 5 years by the UK Research and Innovation (UKRI). The primary purpose of the NQCC is to fill a key gap in the research and innovation landscape addressing the challenge of scaling quantum computing.

The NQCC's initial 5 years will focus on developing a Noisy Intermediate-Scale Quantum (NISQ) machine to demonstrate the technology. The initial technology focus of the NQCC will be to develop superconducting and trapped ion hardware, with prototype projects being commissioned from 2021 onwards.

The NQCC will give assured and direct access to developers and promote the formation of a strong UK-based quantum computing supply chain, whilst driving efforts towards a universal fault tolerant quantum computer.

$10bn Global quantum technology investments announced since January 2020	**£93m** UKRI investment in NQCC	**19** Number of UK quantum computing related start-ups	**£20-35bn** Projected market impact of quantum computing applications by 2027
£1bn Projected quantum computing product & services market by 2027	**300** Partners collaborating as part of the UK quantum hub network	**£1bn** UK 10 year investment commitment to quantum technologies since 2014	**> £135m** UK start-up investment raised

National Quantum Computing Centre

Introduction

The National Quantum Computing Centre seeks to enhance the UK's global leadership in quantum computing, to help translate UK research strengths into innovation, and enable the creation of the first generation of quantum computers, helping to build a resilient future economy. The NQCC is funded through the UKRI, and is dedicated to accelerating the development of quantum computing by addressing the challenges of scaling – technological and user adoption.

The NQCC is a part of the National Quantum Technologies Programme (NQTP), which has already established the UK as a quantum technology global leader. Through its combined £1bn of public and private sector investment over 10 years (2014-2024), the programme will develop and deliver quantum technologies across the areas of sensing, timing, imaging, communications and computing.

The centre will be headquartered in a purpose-built facility at the Science and Technology Facilities Council (STFC)'s Rutherford Appleton Laboratory Campus in Oxfordshire. The centre is due for completion in mid 2023.

UKRI Mission

To ensure that world leading research and innovation continues to grow and flourish in the UK. To support and help to connect the best researchers and businesses.

NQCC Vision

To place the United Kingdom at the forefront of quantum computing, where government, academia and industry work collaboratively to develop quantum computing, securing this strategically important technology for the benefit of the UK.

This will be a world class centre, where world class people will drive activities towards giving the UK a leadership position in quantum computing.

To deliver this vision, NQCC will lead the development, application and commercialisation of quantum computing, accelerating the growth of UK business and the quantum supply chain.

Centre Location

Aerial view of the Rutherford Appleton Laboratory (RAL) Campus.

Aerial view of the NQCC site within the RAL Campus.

The NQCC facility is marked in red boxes (R stands for RAL building).

The new facility will be located at the STFC's Rutherford Appleton Laboratory Campus (RAL) at Harwell in Oxfordshire, a key UK innovation hub. Harwell is a science and technology campus with world-leading facilties and expertise. The campus is creating a place where professionals from around the world come to collaborate and work, with amenities including nurseries, sports facilities, cafés, post office, mini supermarket, weekly pop-up food stalls and attractive public spaces.

The campus, just 20 minutes drive away from Oxford. South Oxfordshire was recently named as the rural area with the best quality of life in Great Britain and national surveys regularly rate the city of Oxford and the county of Oxfordshire very highly for residents' quality of life. Surrounded by beautiful countryside, the campus is within easy reach of picturesque towns and villages, including the historic centre of Oxford to the north and the quintessentially English market town of Newbury and its famous racecourse to the south.

Sponsors & Partners

The NQCC is a flagship programme that builds on prior investments through the UK National Quantum Technologies Programme. The NQCC aims to build on the strengths in quantum computing that the UK has established through the first phase of the NQTP. It will form a key part of the wider QC landscape of the UK, including the Quantum Technologies Research Hubs, quantum challenges and programmes within the Industrial Strategy Challenge Fund, doctoral training, and the activities of the emerging quantum industrial sector.

The Centre aims to bring together academia, business and government to address key challenges such as scaling. The Centre will also provide research institutions, industry and end-users with early access to quantum computing resources as they are developed around the world. This will enable them to explore its potential to develop use-cases and applications. In supporting the government's ambition to establish the UK as the world's first quantum-ready nation, the NQCC seeks to accelerate the quantum computing roadmap towards commercialisation of the technology.

UK Research and Innovation

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

Our Sponsors

Engineering and Physical Sciences Research Council

Science and Technology Facilities Council

Our Partners

GCHQ

dstl

Department for Business, Energy & Industrial Strategy

Innovate UK

Quantum Computing & Simulation Hub

NPL National Physical Laboratory

Governance

The NQCC is managed through a Programme Delivery Board that delegates the day to day management of the Centre to the Leadership Team via the Director. Oversight is maintained through our Programme Advisory Committee and Technical Advisory Group providing advice, support and challenge on the activities of the NQCC to the Leadership Team. Governance is assured through monitoring and evaluation to Engineering and Physical Sciences Research Council (EPSRC) and Science and Technology Facilities Council (STFC). The NQCC Director sits on the Operations Board of STFC and on both the NQTP Programme Board and NQTP Strategic Advisory Board.

Leadership Team

Dr Michael Cuthbert

Director

With a background in superconductivity and cryogenic systems, Michael has had a number of technical and commercial leadership roles with Oxford Instruments in Japan, US and the UK, most recently as Head of Quantum Technologies. Michael is a member of the Institute of Physics and sits on several advisory panels.

Ash Vadgama

Deputy Director for Operations

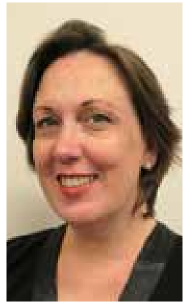
Ash has worked within High Performance Computing (HPC) for over 30 years for UK Government. He led early developments in secure Linux clusters, petascale HPC systems and resilient facilities, as well as collaborations with US national laboratories and other international partners on a variety of emerging technologies. Ash has extensive experience in business leadership, HPC programmes and finance.

Dr Simon Plant

Deputy Director for Innovation

Simon has a background in technical research related to quantum technologies (QT), and has worked in various roles in higher education, government and the public sector delivering research, policy and strategies towards their commercialisation. He was previously the technology lead at Innovate UK responsible for shaping and implementing the UK's innovation strategy for the commercialisation of QT.

Programme Advisory Committee



Professor Sheila Rowan

Chair

Professor Rowan is an experimental physicist, and since 2009, Director of the Institute for Gravitational Research in the University of Glasgow in the UK. She was elected to Fellowship of the Royal Society of Edinburgh in 2008, and awarded Fellowship of the American Physical Society in 2012. She received the Hoyle Medal and Prize of the Institute of Physics in 2016 in recognition of her pioneering research on aspects of the opto-mechanical technology of gravitational wave observatories.

Professor Sir Peter Knight

Sir Peter Knight is Emeritus Professor at Imperial College, a past President of the Institute of Physics and of the Optical Society of America, chairs the National Quantum Technology Programme Strategy Advisory Board and the Quantum Metrology Institute at the National Physical Laboratory.

Professor Tom Rodden

Professor Rodden is Chief Scientific Advisor for the Department for Digital Culture Media and Sport and a Professor of Computing at the University of Nottingham. His research is highly interdisciplinary, bringing together a range of disciplines as computing becomes a ubiquitous feature of our world and we increasingly use personal data and AI technologies.

Roger McKinlay

Roger McKinlay is the Challenge Director – Quantum Technologies for UK Research and Innovation. He has been involved in the National Quantum Technologies Programme since 2015, and was a panel member of the 2016 Quantum Technologies Blackett Review. Roger is a Chartered Engineer and a past president of the Royal Institute of Navigation.

Dr Michael Groves

Dr Groves is Head of the Heilbronn Institute for Mathematical Research. He has worked as a security researcher at Government Communications Headquarters (GCHQ) for over 25 years and served as Vice Chair of the ETSI quantum-safe cryptography working group from 2015-19.

What is Quantum Computing?

Quantum computers operate in a fundamentally different way to conventional digital computers. Quantum computing is based on the rules of quantum mechanics, harnessing effects that exist at the level of atoms, electrons and photons. It involves encoding and processing information by controlling quantum states, relying on the uniquely quantum phenomena of superposition and entanglement.

Qubits

In conventional computing, information is encoded as binary digits or 'bits' – a basic unit of information – that can be represented as either a '0' or '1'. In quantum computing the equivalent unit is a quantum bit or 'qubit', which can exist either in a state uniquely as '0' or '1' or as a simultaneous combination of both '0' and '1', owing to superposition.

A register can be constructed from multiple qubits, which can then become correlated with each other in a subtle and powerful way that cannot exist in the ordinary, classical world – this is called quantum entanglement. The combination of superposition and entanglement means that a quantum register can encode information in a large number of states simultaneously.

This feature is crucial in enabling a quantum computer's power, allowing it to perform computations for tasks that are intractable for even the largest current supercomputers.

Full Stack/Architecture

Quantum computers can have different architectures, being based on alternative designs and constructed in different ways. As with conventional computers, there are several hardware and software layers involved in constructing a quantum computer, that go from the processor through to the user interface – this is referred to as the full stack. Current leading architectures for qubit development across academic and industrial programmes are; trapped ions, superconducting circuits, spins in silicon, cold atoms and photonic devices.

Applications

The availability of quantum computing is expected to impact many sectors, enabling improvements in efficiency, productivity and competitiveness, as well as the creation of new products and services. Promising early applications include:

- The modelling and analysis of more complex molecules to accelerate the discovery of new materials and pharmaceuticals
- The optimisation of complex planning and scheduling for logistics
- Enhancing the design and manufacturing processes in sectors such as aerospace and automotive
- The optimisation of networks; the routing of traffic, telecommunications and energy distribution

Technical Challenges

There are several candidate hardware architectures on which to base quantum computers, each with their own merits and at various stages of technology maturity. The common feature is that physical qubits are inherently fragile, requiring precise control and protection from the external environment. The states need to be as long-lived as possible and the operations on them high-fidelity, otherwise errors accumulate, and more computational resource is required for error correction. Architectures that require limited or even no error correction are being investigated. Technical hurdles have continually been overcome as the field has advanced, but there are significant engineering challenges that lie ahead in scaling to ever greater numbers of qubits with low noise. We also need to learn more about the merits of the different hardware architectures as quantum computers are scaled. A real breakthrough would be to build and demonstrate quantum computers that provide enhanced performance for a range of different tasks. In the near term, we can explore how to tackle some of these challenges by developing NISQ (Noisy Intermediate-Scale Quantum) machines, which can provide a pathway to a general-purpose quantum computer in the future.

National Quantum Computing Centre

The International Landscape

There are a growing number of international programmes, research groups, start-ups and industrial players across the quantum technologies landscape.

Over $10bn of new public investment has been announced since January 2020 with over $1bn awarded through public competitions and a similar amount raised in private capital in the same time period. Global annual public sector spend has more than doubled since 2015.

An analysis of metrics by the NQCC suggests the UK is joint fourth in quantum programme delivery and second in quantum technology commercialisation.

	Governmental spend (2021)	Research publications	Patent applications	2021 ranking
China	1	4	1	1
USA	2	1	3	1
Germany	3	2	4	3
United Kingdom	5	2	9	4
Japan	8	6	2	4
France	4	6	10	6
Canada	10	5	8	7
Australia	9	11	7	8
Italy	12	8	12	9
South Korea	15	13	5	10

	Corporate Engagement	Number of Start-ups	Start-up Capital Raised	Supply Chain Maturity*	2021 ranking
USA	1	1	1	1	1
United Kingdom	3	2	3	3	2
Canada	-	3	2	4	3
Japan	4	6	7	6	4
France	5	5	8	5	4
China	2	8	9	7	6
Germany	5	4	16	2	7
Australia	-	8	4	9	8
Italy	-	14	20	9	10
South Korea	-	23	20	-	10

** excluding nanofabrication infrastructure*

References:

The Quantum Insider

Mathew Alex, Quantum Technologies: A Review of the Patent Landscape

www.Patinformatics.com/quantum-computing-report

Michel Kurek, Quantum Technologies Patents, Publications & Investments

Aim & Objectives

Working with partners across industry, government and the research community, the NQCC will create the necessary R&D capabilities through greater co-ordination (leadership, management, expertise) and delivery of a technical programme, alongside the commissioning and operation of new facilities, to deliver the first quantum computers for the UK. This will enable the UK to remain internationally competitive in this rapidly accelerating field, to the benefit of national prosperity and security, supporting ground-breaking businesses and backing long-term growth for the UK economy.

This will attract industry investment, raise awareness and build skills to make the UK economy quantum ready, and support the growth of the existing supply chain of companies operating in this area to build a sustainable industrial capability in the UK.

By developing the next generation of computing innovation capabilities, the NQCC activities will contribute to the to the objectives set out in the government's R&D Roadmap and Innovation Strategy, and to the societal challenges facing the UK in areas such as the digital economy, energy, healthcare productivity and climate change.
The NQCC's initial 5 years (the scope of this programme) will focus on developing early stage quantum computing platforms to demonstrate the technology, give assured and direct access to developers, and promote the formation of a strong UK-based QC supply chain. This will drive efforts towards a fully scalable, fault-tolerant, general purpose quantum computing capability for the UK.

By the end of this programme, the NQCC will have been established as a world class centre, giving the UK a leadership position in QC and driving activities to build, in the longer term, one of the world's first universal quantum computers. It will build on the strengths in this area that the UK has developed through the NQTP and establish an assured capability in this technology in the UK that goes beyond its initial five-year period. This will enable the construction of increasingly powerful quantum computers, and create a sustainable quantum computing industry.

Opportunity

The UK Economic Potential

Quantifying the future market opportunity for quantum computing is challenging whilst the technology remains immature. However, its economic impact is expected to be wide-ranging and transformative; it has the potential to create new markets and disrupt existing ones.

The BCG Henderson Institute predicts three phases of quantum computing identified as 'early prototypes' (also termed NISQ-era); 'intermediate QC' (also termed Quantum Advantage); and 'general-purpose QC' (also termed Universal Fault-Tolerant). The availability of quantum computing during these phases will impact many sectors, enabling improvements in efficiency, productivity and competitiveness as well as the creation of new products and services.

In particular in the UK, there are many companies with a strong presence that could potentially benefit, including those in new materials, pharma, chemicals, energy, aerospace, defence and financial services. The potential end-users are only just beginning to consider the technology and the impact it will have on their operations.

Of the key quantum computing end-user target sectors, financial services, chemicals, pharmaceuticals and energy contributed over £260bn to the UK economy. Consequently, the UK QC market is anticipated to grow rapidly.

Secondary positive societal impacts on healthcare, renewable energy, clean air and reduced power consumption offer additional long term promise.

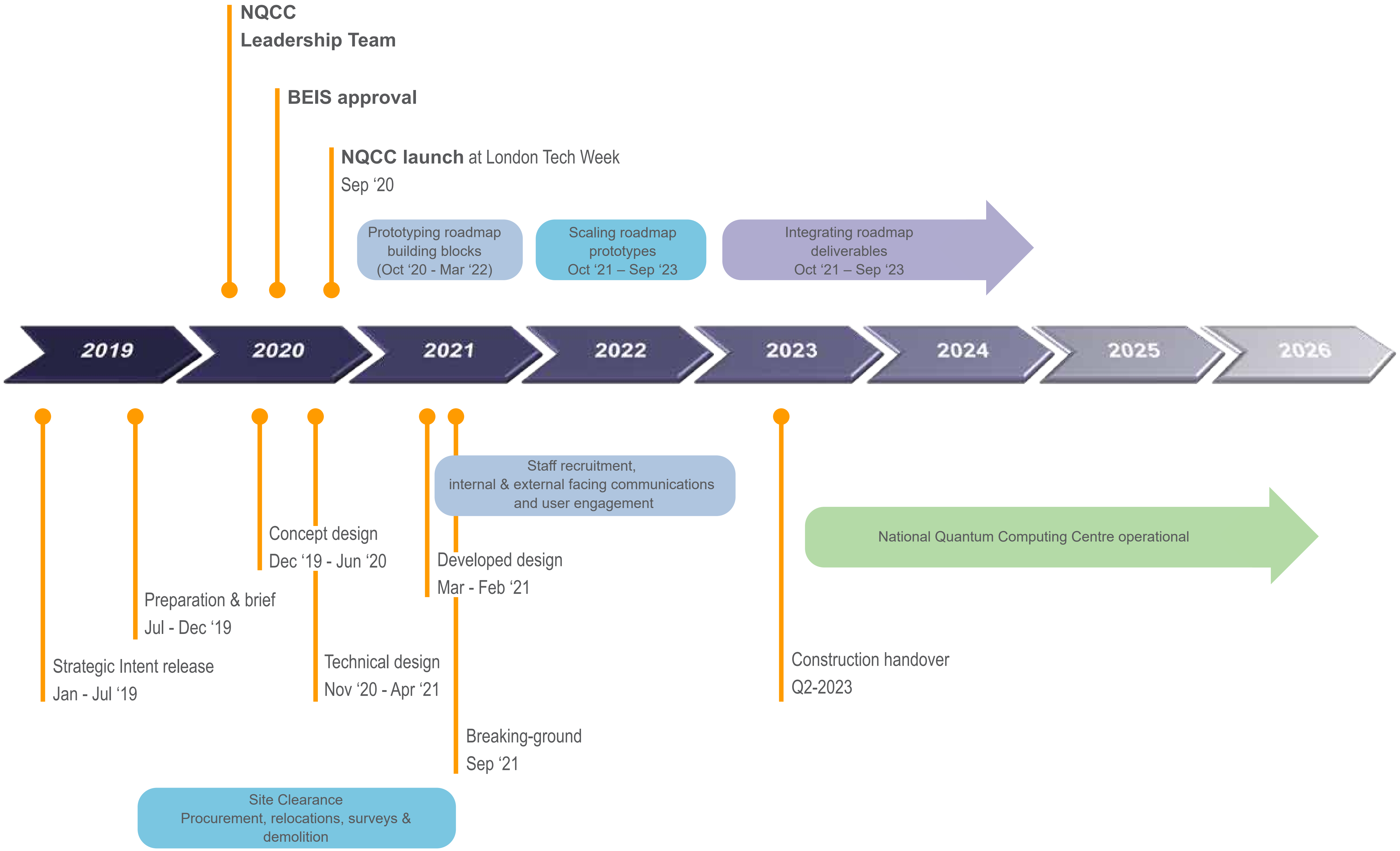
Early adopters stand to gain expertise, market visibility, intellectual property and structural preparedness ahead of widespread adoption, however this is a long term endeavour.

The Global Economic Potential

Despite the technology still being in the early NISQ-era with many technological and engineering challenges to overcome, the global economic potential is exciting too. The improvements in efficiency, productivity and competitiveness as well as the creation of new products and services have led to recent estimates which indicate that $5-10 billion could be realised by technology providers and endusers over the next 3-5 years. This assumes the technology scales at the predicted pace. In the longer term, it's been estimated that QC has the potential to generate a value between $450-850 billion annually over the next 15-30 years as we move towards practical, general-purpose quantum computers.*

*Jean-Francois Bobier, Antoine Gourevitch, Matt Langione and Edward Tao (2021). What Happens When 'If' Turns to 'When' in Quantum Computing? BCG.

Programme Timeline

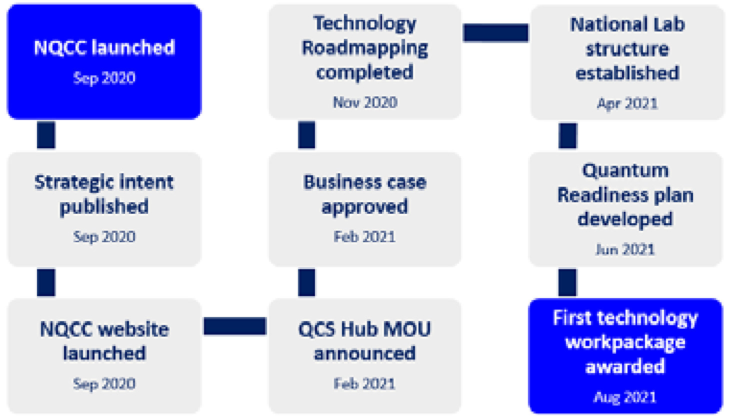


National Quantum Computing Centre

Programme Progress

Programme Development

During its foundational year, the early programme focus was on business case approvals through government, technology roadmapping, technical work package specification and establishing the Centre as a new national laboratory. In the second half of the year, emphasis switched to work package procurement, quantum readiness engagement, collaborations and recruitment.



Recruitment

Our drive to build a team of around 65 people is ongoing with recruitment initiated this year. The leadership team were appointed in Spring 2021. We are delighted to welcome our growing team to the NQCC.

Facility

The work on the facility commenced in November 2020, with the start of the demolition and site clearance. The Vale of White Horse District Council granted planning permission for the NQCC facility in April 2021.

National Quantum Computing Centre

Collaborations

Quantum Computing & Simulation Hub

National Quantum Computing Centre

Under a Memorandum of Understanding (MOU) announced on 16th February 2021, the National Quantum Computing Centre and the Quantum Computing and Simulation (QCS) Hub pledge to work together to advance the field of quantum computing for the benefit of the UK and unlock the advantages for wider society. The two organisations will endeavour to pursue joint research and build the future workforce, by promoting the mobility of researchers working on collaborative projects, supporting training schemes and sharing access to their facilities.

This MOU strengthens a shared vision, recognising the profound impacts quantum computing is expected to have in advancing knowledge and scientific discovery, and for realising economic and societal benefits.

The NQCC and the QCS Hub are part of the UK's National Quantum Technologies Programme, an integrated research and technology programme with a 10-year vision for making the UK a 'quantum ready' economy. Between 2014 and 2024, £1bn of public and private investment will be committed to this endeavour.

The QCS Hub is a collaboration of 17 universities, supported by over 25 commercial and governmental organisations, with the University of Oxford as its lead partner.

Funded by the UKRI-EPSRC, it is one of four hubs in the UK's National Quantum Technologies Programme. Focussed on overcoming the key challenges required to accelerate progress in quantum computing and simulation, the Hub aims to help position the UK at the forefront of the global competition to build a universal quantum computer. To achieve this the Hub is working with an extensive network of academic, industrial and governmental organisations.

Research within the Hub includes both hardware and software, and ranges from core technologies to potential applications. By proactively cultivating an environment in which researchers can engage with the world of commerce and entrepreneurship, the Hub's activities promote the real-world potential of quantum computing and the important part its early adoption can play in the UK economy.

Our People

The NQCC is committed to building a world-class team of talented individuals and will present an exciting opportunity for those wanting to work in the quantum computing sector, to develop and enhance their careers in a fast-paced, dynamic and innovative environment. The Centre will offer an excellent networking opportunity to collaborate with various partners. It aims to attract interest from across the globe, making the NQCC a go-to place for quantum computing research and development.

Recruitment Roadmap

H1 2021

Stage 1 Recruitment

Leadership Team
- Director
- DD Innovation
- DD Operations
- DD Research

Programme Team
- Programme Manager
- Facility Manager
- Quality Officer
- Communications Officer
- Business Development Manager

Technology Team
- Ion Trapping Hardware Development Manager
- Superconducting Hardware Development Manager
- Quantum Systems Development Manager

H2 2021

Stage 2 Recruitment

Programme Team
- IT Specialist
- Office Manager
- Project Managers

Technology Team
- Systems Architect
- Hardware Development Engineers
- Software Development Engineers
- Optical Physics Specialist
- Cryogenic Engineering Specialist
- Applications Specialist

H1 2022

Stage 3 Recruitment

Leadership Team
- Chief Scientist

Programme Team
- Business Development Manager

Technology Team
- Algorithm Developers
- Firmware Engineers
- Electrical Engineers
- Hardware Development Engineers
- Software Development Engineers
- Applications Specialist
- NQCC Fellowships

H2 2022

Stage 4 Recruitment

Programme Team
- Facilities Technician – Electrical
- Facilities Technician – Mechanical
- Security Officer
- Safety Officer
- Business Development Manager

Technology Team
- Advanced Technology Leader
- Hardware Development Engineers
- Software Development Engineers
- Applications Specialist

H1 2023

Stage 5 Recruitment

Programme Team
- User Services Manager

Technology Team
- Lab Technicians
- Hardware Development Engineers
- Software Development Engineers
- Staff Scientist
- NQCC Fellowships

National Quantum Computing Centre

Facility Design & Sustainability

Design Objectives

- To create a building that is responsive to the changing needs of developing and evolving quantum computing systems, including the development of software and algorithms
- To create a prominent landmark, inviting external specialists to spend time at the campus
- To provide a high quality lab space and a secure and assured working environment
- To create a facility that fosters collaboration between software and hardware researchers
- To provide a suitable working environment for professional people in a highly competitive landscape
- To create a facility that supports world-class research and presents itself as the UK's home of quantum computing
- To provide a facility that inspires pride in the UK programme and attracts global talent to the UK and to the NQCC.

Sustainability Principles

- Achieving a BREEAM sustainability rating of 'Excellent'
- Following the recognised energy strategy hierarchy of 'Be Lean, Be Clean, Be Green'
- Minimising energy use and CO_2 emissions through the incorporation of highly efficient building materials with a focus on lighting and ventilation
- Maximising energy efficiency features and integrating low carbon energy through the use of air source heat pump and photovoltaic panels
- A combustion-free development to minimise the impact on local air quality
- Achieving a minimum of 40% reduction in regulated CO_2 emissions on-site through renewable and low carbon sources
- Maximising recycling of construction waste to reduce the carbon footprint.

Dedicated to sustainable research from day one.

National Quantum Computing Centre

Enabling Works & Site Clearance

The NQCC is a UKRI centre sited on the STFC facility within the Harwell campus offering an attractive environment for incubation of new businesses. The campus is well located in terms of the industrial landscape of emerging suppliers and existing users, and is co-located with some of the key academic strengths within the quantum computing community along the M4 corridor including University of Oxford, Bristol and Imperial College London. The Centre will leverage other capabilities on the Harwell site including its wide range of facilities, collaborative spaces, emerging businesses, accommodation and smart transportation.

The design and development for the facility started in early April 2020, during an unprecedented time for the UK due to the pandemic lockdown. The NQCC Project, Design and Build Teams comprising architects, engineers, designers, planning and estate personnel, all came together to finalise the design the NQCC facility, whilst many of the team worked from home.

The NQCC was supported by Subject Matter Experts on all aspects of the facility design drawn from across the UK industry and academia. With their help and support, the NQCC facility is designed to house many different technologies based upon a variety of quantum computing architecture designs.

Despite the ongoing challenges of the global pandemic, the use of online communications and tools allowed significant progress to be made keeping site preparations on time as can be seen in these pictures.

Today, the ground has been cleared and is ready for main construction programme to begin, which is due to complete in mid 2023.

Programme Update

Design update

The NQCC project was structured in accordance with the Royal Institute of British Architects (RIBA) Plan of Work 2013.

Hawkins\Brown are appointed as the Principal Designer on the NQCC construction project.

Preparatory design work maintaining a design-based focus on risk prevention and safety.

Work on RIBA Stages 0-2 were completed between Jan and Aug 2020.

Detailed design work was completed between Aug and Dec 2020, taking concept designs through to detailed room layouts underpinning the technical requirements and delivery of the NQCC.

Following the design freeze and planning consent at RIBA 3 the design team have been working with pre-construction partners to generate a detailed construction design model, procurement work packages and ensure cost and time estimates are robust, achievable and risk managed.

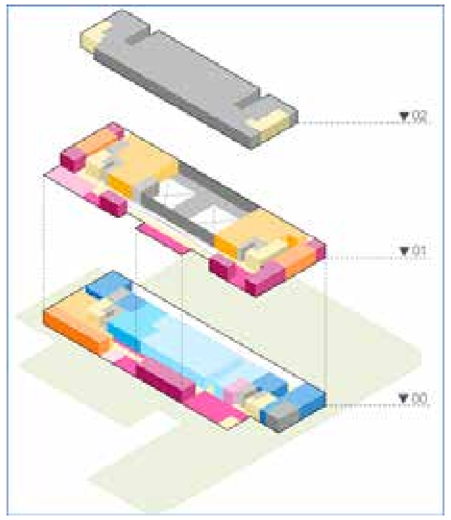
The NQCC construction will deliver a 4000 square meter two-storey building to provide office and laboratory floorspace (Use Class B1). This is supported by servicing, landscaping works, cycle parking, provision of utilities and other infrastructure. The NQCC is a linear block of east-west orientation comprising of two storeys of occupied accommodation, with a set back plant enclosure at second floor level. Its primary function is to provide flexible research laboratory and office space. The total building footprint is 77.1m x 25.9m, with a common structural grid of 6.6m x 6.6m applied throughout. The storey heights are driven by the proposed use, the floor to soffit heights are consistently 4m on all floors, with laboratories slightly higher for plant equipment. The overall building height is 14.2m (excluding flues).

Ground floor
The ground floor is largely taken up by research laboratory accommodation to the north. A small strip of offices, large seminar, meeting, collaboration, and reception spaces run along the south. A linear atrium connects the ground floor with the first floor above, providing an airy, open and light space.

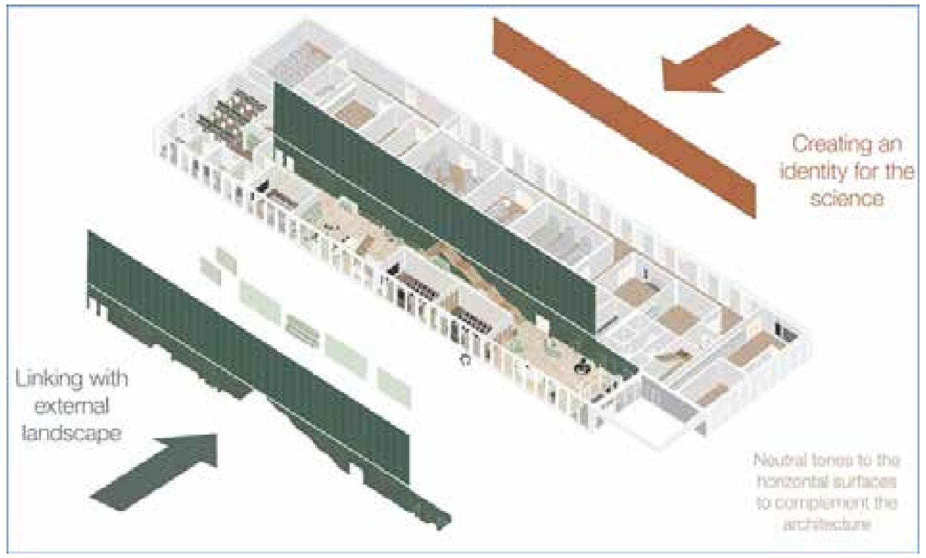
First floor
The first floor accommodates large, shared research office spaces looking north and smaller cellular office spaces to the east and west ends of the building. A strip of meeting and collaboration spaces run along the south.

Second floor & Roof
The second floor level accommodates the set back Plant enclosure and Photo-Voltaic (PV) Solar panels which are also located and accessed from this level.

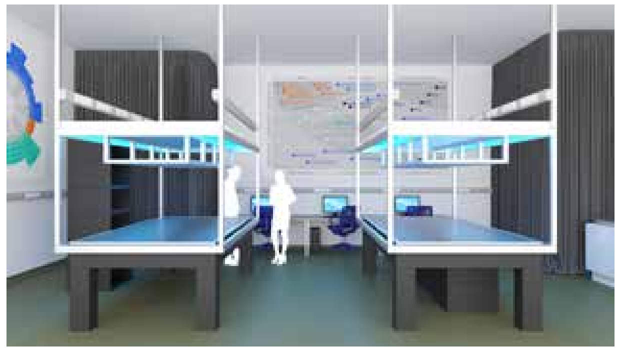
Floor Zoning Key



Building Accommodation and Layout with Floor Zoning Policy



Interior Design Strategy - Design Principles – Axonometric



Breaking-ground Event

Ground was broken on the 20th of September 2021 at the Harwell Campus, ahead of construction commencing. Professor Sir Peter Knight, Chair of the NQTP Strategy Advisory Board led the ceremony with Professor Mark Thompson, Executive Chair STFC, Professor Dame Lynn Gladden, Executive Chair EPSRC and representatives from across the UK quantum sector and government present.

Breaking-ground Event

Building a Quantum Future

"Construction will soon be starting on the UK's national laboratory dedicated to quantum computing. With funding of £93m over the next five years, the primary objective of the UK's National Quantum Computing Centre (NQCC) is to accelerate the scale-up and exploitation of practical quantum computers".

IoP Publishing, Sep 2020.

Engagement, Outreach & Communications

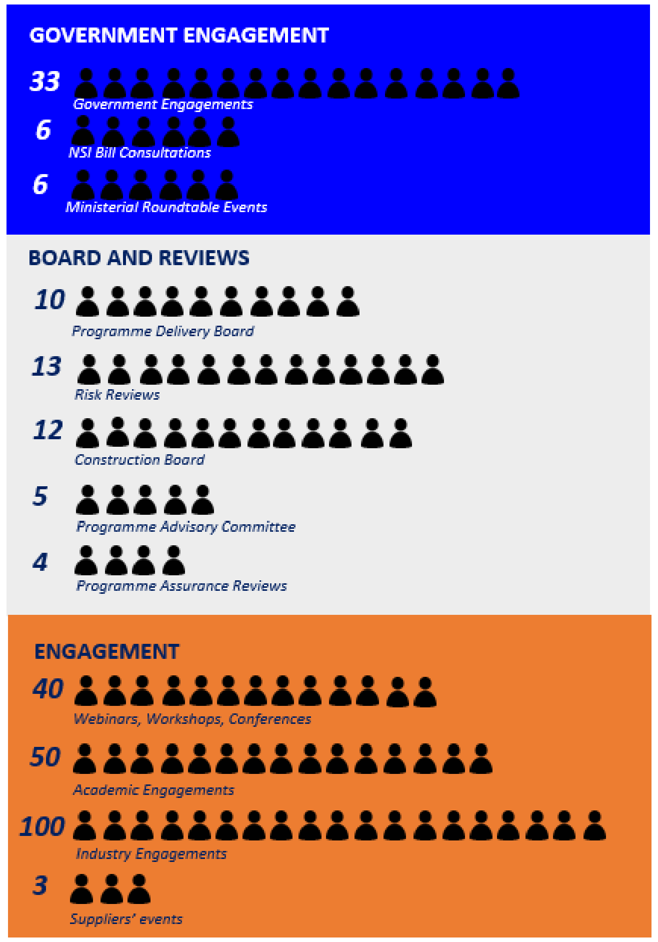
An important role of the NQCC is to engage with a wide variety of interested parties, ranging from companies and universities, to government bodies and end-users. An important purpose of the centre will also be to train and educate skilled individuals and inspire the next generation of scientists and engineers. The NQCC builds upon and takes advantage of the knowledge within the National Quantum Technologies Program, the Harwell Science Campus and the Quantum Computing and Simulation (QCS) Hub.

The NQCC is an enabler of a quantum-ready economy. It offers several entry-points into the field of quantum computing:

1. Access to quantum computing resources
2. Education and training
3. Technical support and user-case exploration and development
4. Workshops, tailored networking events and hands-on hackathons

If you are interested in shaping the quantum future with us, sign up at www.nqcc.ac.uk/engage-with-us

Over **10,000** engagement interactions	Participated in London Tech Week, Quantum.Tech and the National Quantum Showcase	Signed up with **5** collaborative programmes	Launched EPSRC Fellowships
More than **10** external quantum events	**3** general public outreach talks delivered	Sponsored **4** articles and **1** video	Co-chaired **3** ministerial roundtables



Outreach and Education

The NQCC will provide educational resources for students as well as teachers across the UK. It will also engage the public through outreach talks, presence at science festivals and a series of public lectures. In autumn 2021, the NQCC delivered its second outreach talk to the Didcot University of the Third Age community. The NQCC is a gold sponsor for the 'Quantum on the clock' video competition organised by Institute of Physics.

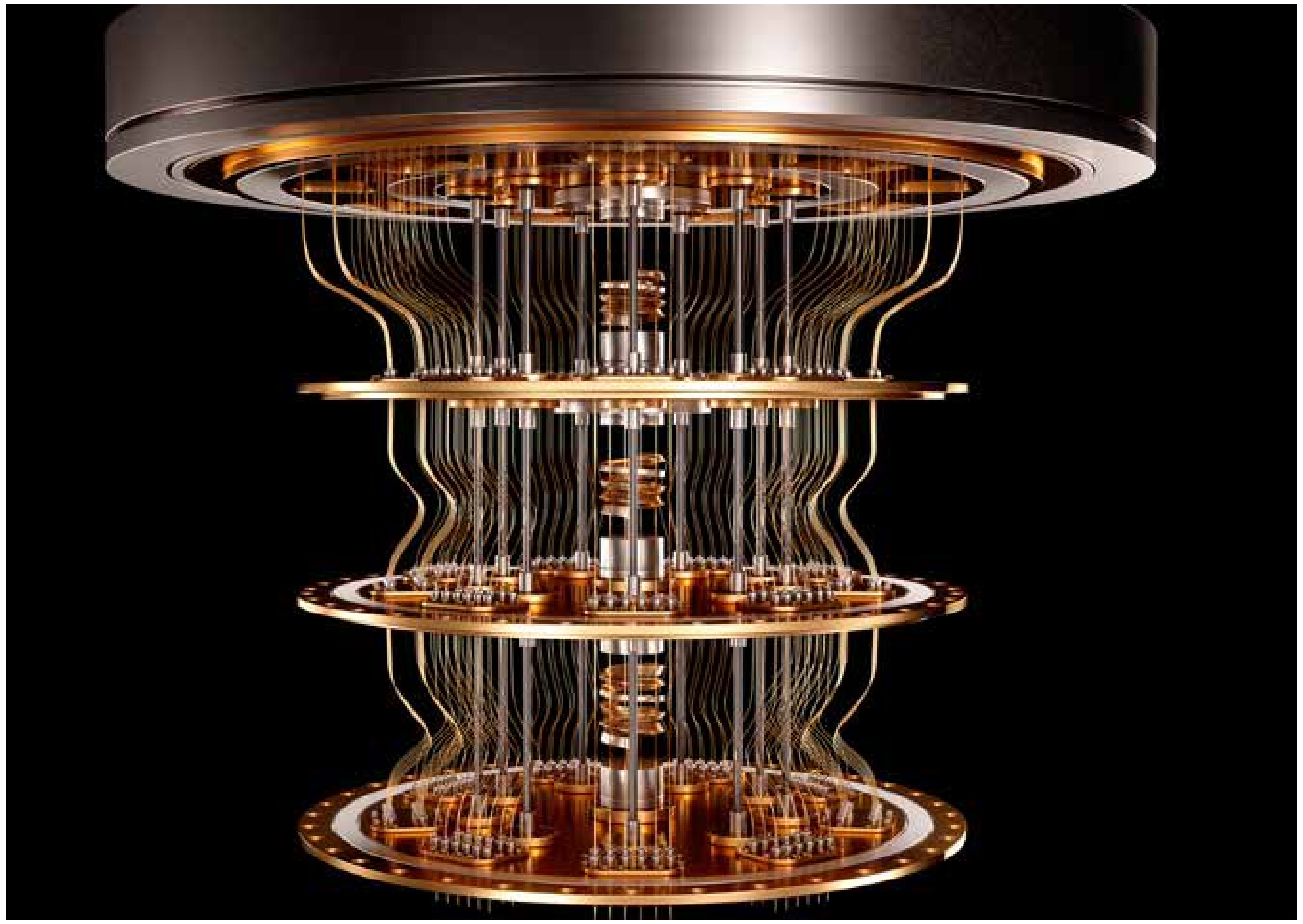
Fellowships

In order to support research in quantum computing, several of the awards made through the EPSRC Quantum Technology Career Development Fellowships will be supported by the NQCC. This call ran from Aug to Oct 2021 with successful awards to start in Apr 2022. Researchers seeking to work with NQCC were encouraged to focus on aspects of quantum computing, such as algorithm development, standards, benchmarking and simulation.

To support these positions, access to prototype hardware will be available through the NQCC.

Other areas of underpinning technology such as control systems and theory, materials for quantum computing platforms and device development, were also encouraged.

Quantum Readiness



Quantum computing has a formidable ramp-up challenge. Programming the quantum stack represents a significant shift from conventional computing. Therefore, the existing computing resources, skills and teams will not make the transition on their own. Early adopters stand to gain expertise, market visibility, intellectual property and structural preparedness ahead of widespread adoption However, this is a long-term endeavor with the timing of technology breakthroughs uncertain. Therefore traditional technology adoption models are unlikely to be observed. The innovators to laggards stages are more likely to be skewed to the later stages, as awareness and capability develops.

For some industrial sectors, who are already using of high performance computing, QC represents a clear opportunity with internal development teams and technology advocates already in place. For them the critical pivot point comes when they transition from a research focus to operational delivery. By integrating the enhanced capabilities of QC into their existing business models they will seek to create market differentiation. For other sectors QC offers the opportunity to develop new business models. Finally for some sectors QC may appear to offer no competitive advantage, however, the threat that QC may impose on their organisations should also be considered particularly with regard to data integrity and security.

To aid this process the NQCC seeks to support industry through training and outreach, engaging in use case development, and building advocacy within organisations through articulating the benefits of QC..

As the technology develops from the NISQ-era through Quantum Advantage towards Universal Fault-Tolerant quantum computing, engagement with the wider economy will be necessary to act as a source of assurance and to provide impartial support on the requirements to participate.

To support the building of a UK quantum computing user community the NQCC has laid out a five stage end user journey from Awareness through Engagement, Consideration, Action to Advocacy. We see a number of activities associated with each step including sector based events to understand the potential of quantum computing. Across sectors we also expect events and hackathons to explore solutions to real world problems including by solution type – machine learning, optimisation and simulation. The next step is to shape the evolution of these technologies to meet sector needs. This will be facilitated through access to world class resources made available through the NQCC. Finally, the NQCC will grow the end user community, the skills base, the industry participation and the user adoption.
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Throughout this process, we are seeking to maintain a keen eye on the 'right tools for the job' and integrate high performance computing and hybrid quantum-classical resources into the suite of options available to this fledgling user community.

Join the NQCC user community at:
www.nqcc.ac.uk/engage-with-us

An example of early engagement in such exploratory workshops have been a series of Finance sector roundtables and workshops held in collaboration between the QCS Hub, BEIS Technology Strategy & Security Team and the NQCC.

The workshops convened end-users across various banks and financial services organisations, regulators, government, academia and the tech developers. This group worked to understand potential applications, explore solutions and narrow future scope for collaborative working in a competitive environment. Whilst many use cases will generate competitive advantage for individual developers, other examples show opportunity for structural development to the betterment of the whole industry.

Of the many opportunities explored, five key areas looked to generate the most interest across the group. Namely, data privacy; detection and reporting of financial crime; data identification and risk profiling; optimisation processes such as streamlined settlement and portfolio diversification; quantum AI for fraud detection and quantum-resistant cryptography.

Technology Roadmap Development

Through extensive consultation across academia and industry experts, the NQCC has developed a technology roadmap identifying detailed initial steps towards the goal of a 100+ qubit NISQ-era machine by 2025. These first steps will be realised through a series of technology project commissions, ahead of the NQCC facility completion in early 2023. Work streams addressing hardware, software, algorithms and applications have been established. Within these work streams the topics of underpinning technologies, scaling, error and noise mitigation, bench marking and verification as well as solution packaging and user accessibility is being tackled.

The initial focus will be on superconducting and trapped ion qubit platforms as these are currently the most mature. However, the roadmap will be driven over time as a gated process, enabling promising new platforms and technologies to be adopted, and hard decisions made regarding platforms unable to scale to the performance levels needed to deliver universal fault tolerance.

Three critical milestones have been identified as the Centre establishes its technical delivery.

- A NISQ/Quantum Advantage crossing point
- A NISQ-era 100+ qubit machine
- A scalable logical qubit architecture

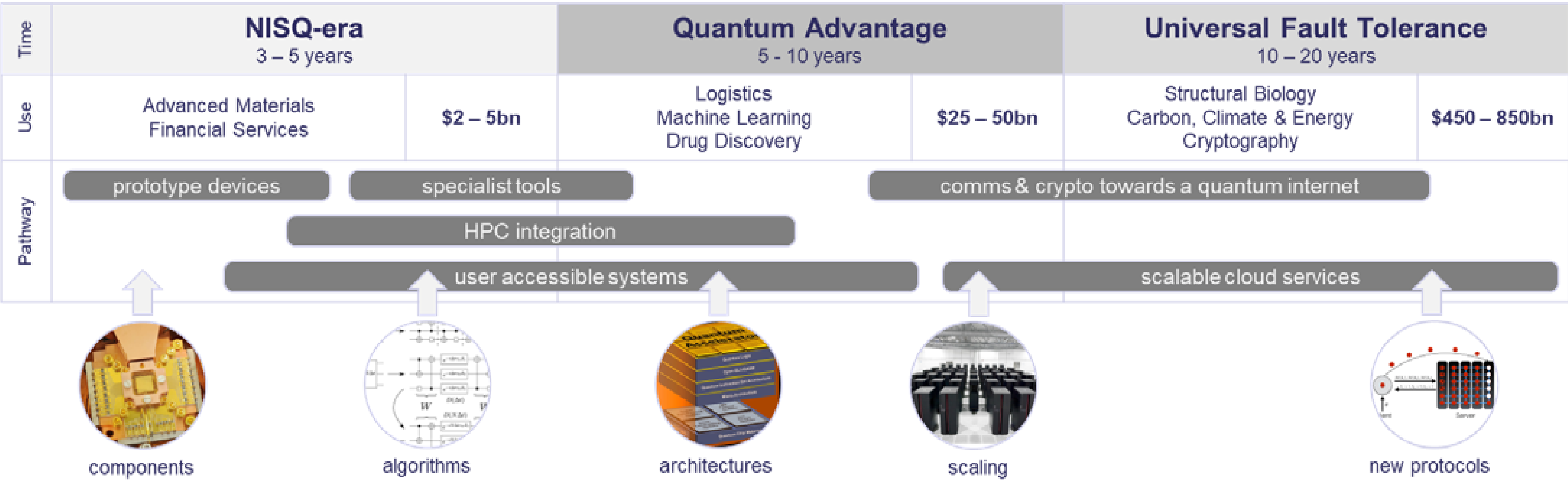
Through verification and benchmarking as well as international participation on identification of QC standards and metrics, progress towards compiler enhanced NISQ hardware is anticipated to be a key aspect of software enhanced hardware performance.

Milestones

- Technology landscape survey completed and Alpha stage technology roadmapping and scoping of work package specifications complete after engagement with subject matter experts across the UK – covering Trapped Ions, Superconducting circuits, Neutral Atoms, Photonics, Spin systems and Software and Algorithms
- Priority work packages identified according to strategic needs
- Launched tenders for the first tranche of technical work packages
- First contract awarded to Riverlane
- Suppliers events held ahead of tender launches.

It is often observed that as technologies are advanced from the innovators and inventors to commercial products and services, there can be a gap in resources transitioning out of research-led activities through technology development stages and into commercial exploitation.

Building a quantum computer requires a number of significant technological challenges to be overcome and demands expertise and capabilities in a broad range of areas across science and engineering. The NQCC seeks to help the emerging UK quantum industry bridge that resource gap. Furthermore, by focusing on technology platforms as they mature enabling scaling, the NQCC fulfills a clear remit within the UK landscape collaborating with academic groups, other national laboratories, start-ups and industrial partners. The NQCC will also identify long-term underpinning technologies required for scaling towards universal fault-tolerant machines of the future and commission early work to ensure these building blocks are in place as they are called for on the roadmap. This will include items such as cryoelectronics, nanofabrication, benchmarking, verification and error correction.



Reference: 'Where will quantum computers create value - and when?' Authors: Matt Langione, Corban Tillemann-Dick, Amit Kumar, and Vikas Taneja. Boston Consulting Group, May 2019,

Work Package Commissioning

Our technology roadmapping activities have identified eight programme deliverables.

For hardware of any technology platform these are:

1. **High Fidelity**: Low noise and increased coherence times to provide for stable qubits capable of long term operation.

2. **Scalability**: Increased numbers of qubits and interlinks to enable circuit and device scaling.

3. **Autonomous Operation**: Scalable control systems capable of operation outside a lab environment.

For software across the stack:

4. **Compilers & Tools**: Progressive abstraction from performance specifics to low-level languages driving new application developments.

5. **Benchmarking**: Documented open source tools and protocols to benchmark and verify emerging quantum hardware & software systems.

6. **Cloud Provision**: Access to UK-based cloud services enabling the research community to explore new science, technical developers to create new algorithms and use cases, and industry to engage in quantum readiness.

Across a range of underpinning technologies:

7. **Robust Supply Chains**: Commercial and sustainable supply of necessary component technologies such as cryo-CMOS, vacuum encapsulation, photonic sources & detectors, mK platforms and high performance electronics.

For a variety of applications bringing societal and economic benefit:

8. **Quantum Advantage**: Use cases with clear and measurable quantum advantage over the best available conventional approaches.

National Quantum Computing Centre

Based on these eight deliverables and after examination of the technology platforms available, an initial set of priorities was determined with a series of work packages specified.

Against deliverable 1:

WP1: In-lab demonstration of an ion-trap system with microwave controlled two-qubit gates at or beyond the fidelity of laser-driven gates, together with a study describing a means to scale its performance to a future system with 1000+ ions.

WP10: In-lab demonstration of a superconducting circuit-based quantum device demonstrating one and two-qubit gate operation against set performance criteria.

Against deliverable 2:

WP2: In-lab demonstration of a trapped ion qubit processor with 10+ qubits and scalable architecture.

WP11: In-lab demonstration of a superconducting qubit processor with 10+ qubits and scalable architecture.

Against deliverable 5:

WP18: Open standards for emerging quantum processors.

WP19: A practical benchmarking suite for open and fair assessment of hardware performance.

Against deliverable 8:

WP20: Detailed investigations of algorithms achieving quantum advantage on NISQ-era devices.

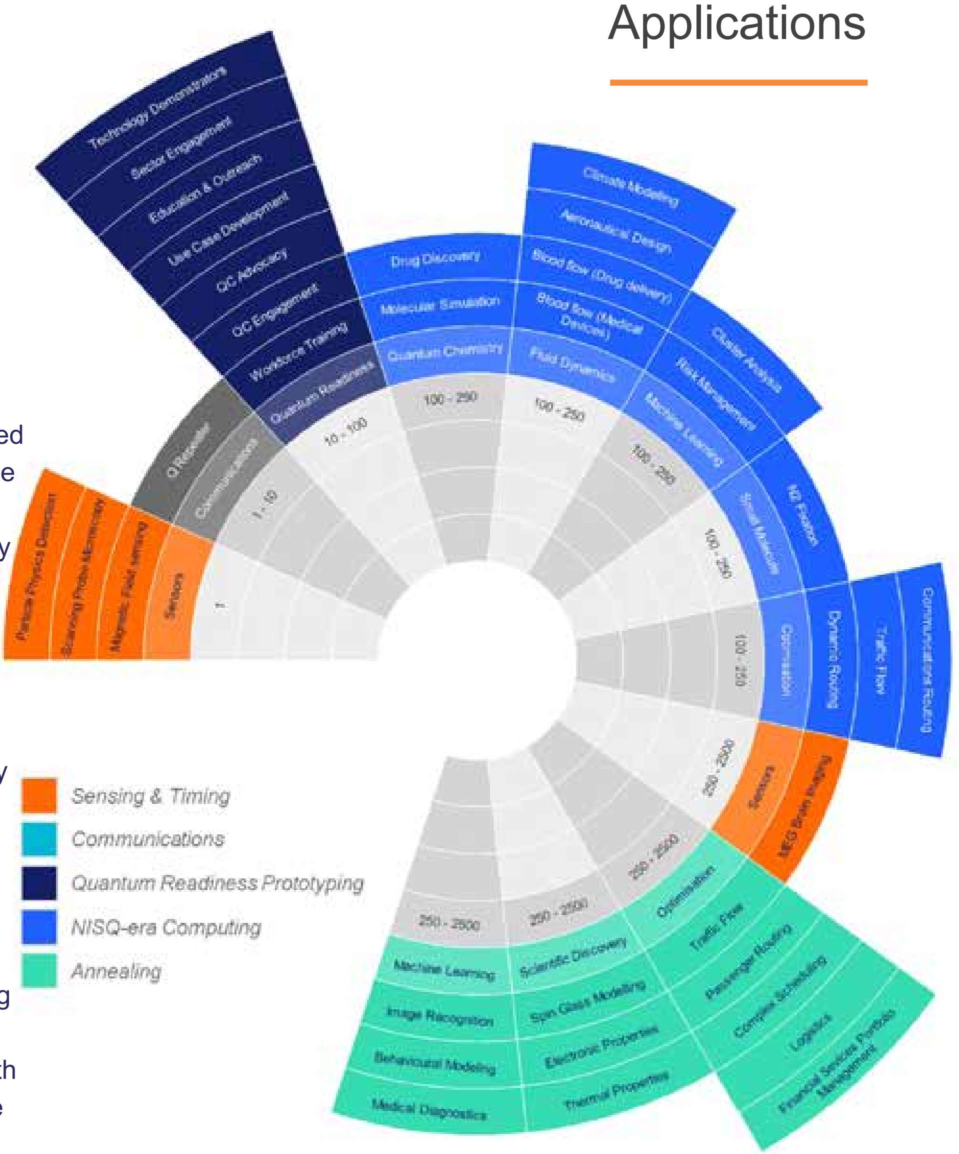
These work packages have been specified to accelerate the technology development in quantum computing systems in the UK. Budgets and timelines have been identified against each work package as laid out in the procurement tendering documentation.

Further detail at www.contractsfinder.service.gov.uk

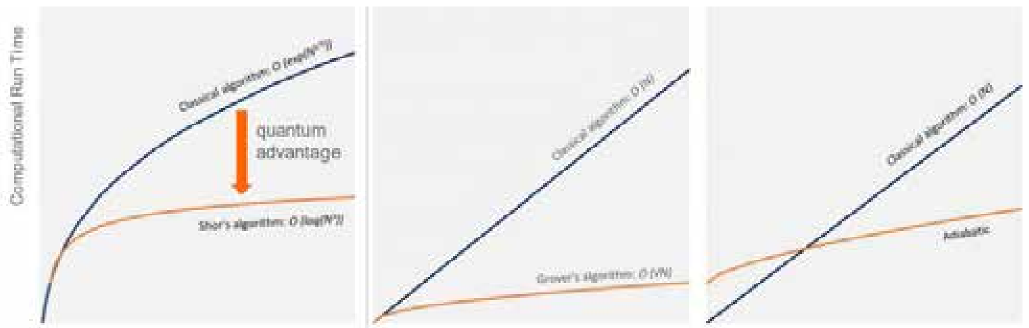
Applications

Through the encoding of entangled states with quantum information, quantum computing has the potential to unlock unprecedented parallel processing. This so-called quantum advantage is evident in the well-known algorithm examples of Shor (factorisation) and Grover (unstructured search). However, quantum advantage is also a function of the number of available qubits and their susceptibility to noise.

Given this potential to accelerate resolution of complex problems and enable previously intractable computations, it is desirable to identify early use cases not reliant on fault tolerance and error correction. Such early examples are to be found in quantum chemistry, fluid dynamics, machine learning, small molecule simulation and optimisation. Annealing processes have shown promise in machine learning and optimisation with qubit arrays of a few thousand. A core element of the NQCC will be to work across industry sectors to develop use cases and value propositions through applications.



Candidate early use-case and applications for NISQ-era qubits & computing



Computational run-time advantage for 3 notable quantum algorithms

Technology

Outlook and Next Steps

2021 saw several key milestones for the NQCC: Programme phase 2 (Centre Launch) moved on to phase 3 (Operational Delivery) following governmental approvals of the business case, recruitment of the leadership team, facility design freeze & planning consent, site clearance and breaking-ground, technology work package commissioning, quantum readiness plans developed and staff recruitment initiated.

In response to the endorsement and feedback from the UKRI Investment Committee, the NQCC is focussing on further development of the programme in terms of:

- Ensuring the application of quantum computing is strongly embedded in the mission and technical programme of the Centre
- Identifying and communicating synergies and interdependencies across UKRI programmes where quantum computing, underpinning technologies (such as nano-fabrication), or skills play an important role
- Considering the long-term sustainability and business model for the Centre including opportunities to attract external investment.

Key activities planned for 2022 include ongoing work package procurement and recruitment as priority activities. Furthermore, release of the facility construction contract will allow construction to start in January.

We are delighted to be joining the QuPharma ISCF consortia due to start work in early 2022.

The EPSRC fellowships sponsored by NQCC will start in April 2022.

Ongoing quantum readiness workshops and hackathons are planned throughout 2022 with a range of outreach and engagement activities in tandem.

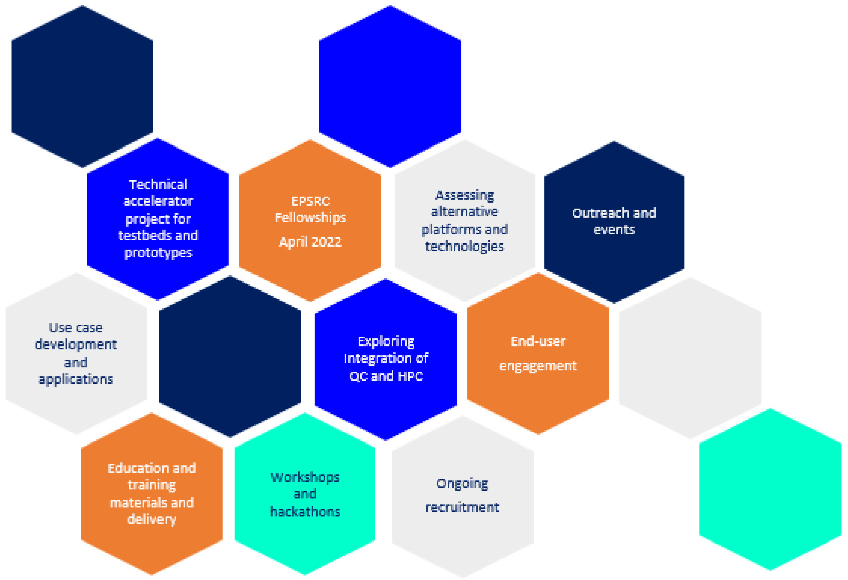
Critical to this delivery is the ongoing access provision of quantum computing resources, creation of training materials and delivery mechanisms, and development of technical support. Driving use case development and application is a key theme for 2022.

Given the pace of development and investment into quantum computing, the NQCC leadership team are exploring opportunities for an accelerator project which will enable access to modest lab and office space to prototype equipment and test beds, ahead of installation into the main NQCC facility. This would also allow for enhanced collaborations with UK quantum start-ups and winning bidders for our work package technology commissions.

Beyond the planned Centre recruitment, we are looking to further cement academic links through the appointment of a Chief Scientist expected to be a joint position with an academic institution, and leading algorithm and quantum information theory activities for the NQCC.

In the technical programme we will be exploring the potential for neutral atom platforms to join trapped ions an superconducting hardware as development priorities. Furthermore we will explore opportunities to accelerate photonic interconnects, sources and detectors as well as engage in the various cryo-CMOS programmes running across the UK. These are recognised as critical underpinning technology building blocks.

Finally, working with colleagues across UKRI we see the development of a multi-faceted user community as the key deliverable for 2022.



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