XPRIZE QUANTUM APPLICATIONS | Google Quantum AI | gesda

Pushing the frontiers of quantum algorithms towards tangible and positive societal impact.

PRELIMINARY COMPETITION GUIDELINES

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XPRIZE Quantum Applications is made possible thanks to the generosity of Title Sponsor Google Quantum AI and additional support from Geneva Science Diplomacy Anticipator (GESDA) Foundation. XPRIZE Quantum Applications is governed by these Competition Guidelines, to be published at the official Competition launch in Spring 2024 following a Public Comment Period. The Competition Guidelines summarize the high-level requirements and rules of the competition. These Guidelines are based upon extensive research and consultation with experts (Appendix B).

XPRIZE may revise these Guidelines at any time during the course of the competition to provide additional information or to improve the quality of the competition. Unanticipated issues that arise may require modifications to these Guidelines. XPRIZE reserves the right to revise these Guidelines as it, in its sole discretion, deems necessary. All **Registered Teams** will be notified of revisions in a timely manner. For further details concerning the operation of the competition, such as exact dates and locations of events, specific technical thresholds for performance testing, and operational information, please refer to the Rules and Regulations, Competitor Agreement, and other documents that will be forthcoming throughout the course of the competition.

The Preliminary Competition Guidelines are open for public comment until March 15, 2024. Please email your questions and feedback to qc-apps@xprize.org.

Background: *XPRIZE is an established global leader in designing, launching, and executing large scale competitions to solve humanity's greatest challenges. Our unique model democratizes innovation by incentivizing crowd-sourced, scientifically viable solutions to create a more equitable and abundant future for all.*

The idea to have a prize in quantum computing originated from a collaboration between XPRIZE and GESDA, as part of the design and incubation of the Open Quantum Institute. Subsequently, Google Quantum AI joined as title sponsor and partnered with XPRIZE to develop our shared vision for a competition. These particular prize guidelines were drafted by Dr. Ryan Babbush (Google Quantum AI) and the XPRIZE Prize Design Team with guidance from an esteemed group of advisors who generously donated their time and expertise (Appendix B).

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Competition Overview

Advances in quantum computation hold promise for addressing complex, societally important problems. Growing investment and recent developments in quantum computers are driving excitement for the feasibility of running calculations far out of reach of classical computers, but there is still a large gap between the ambitious hopes for the impact of this technology and the relatively modest handful of applications that have been thoroughly analyzed and convincingly shown to provide a meaningful quantum advantage for real-world problems.

To realize the transformational potential of quantum, it is necessary to advance the state-of-the-art in quantum algorithms, to scientifically evaluate the benefit that quantum algorithms offer to real-world problems, and to carefully quantify the quantum hardware requirements needed to realize these benefits. XPRIZE Quantum Applications, sponsored by Google Quantum AI, aims to accelerate this process through a quantum applications competition directed towards use cases in sustainability and societal good. Over two competition phases, teams will merge quantum and domain expertise to ideate quantum applications that might impact such real-world problems.

The winning submissions will most accelerate the field of quantum algorithms towards quantum advantage for positive real-world applications. In determining this, our judging panel will weigh a number of factors including most prominently:

A. The projected magnitude of positive real-world impact that would result from quantum advantage in the proposed application area(s).
B. The estimated quantum resources required for quantum advantage (i.e., how near-term?).
C. The strength of the evidence supporting claims for (A) and (B).
D. The novelty of the submission (i.e., magnitude of the "thought delta" introduced).

We expect that competitive submissions will make at least one of the following types of contributions (we also give a few examples from the last five years; however, note that these examples are not in any way an expression of preferred areas of focus):

1. A new quantum algorithm for solving a new class of problems with quantum advantage.

   Example: quartic quantum speedup for tensor principal component analysis (arXiv: 1907.12724). Submission would be incomplete without suggesting a target real-world application and submission would be much stronger with some estimated resources for quantum advantage. Still, significant points for novelty.

2. Work showing how existing quantum algorithms can be used to solve previously unknown applications with a quantum advantage.

Example 1: using quantum linear system solvers or Hamiltonian simulation to give super-quadratic speedup in simulating classical waves (arXiv:1711.05394) or coupled harmonic systems (arXiv:2303.13012). Submissions would be stronger with some estimated resources for quantum advantage in real-world applications.

Example 2: using quantum simulation to better design fusion reactors (arXiv:2308.12352). Weakness is that quantum simulation applications are not especially hard to find and resources required for advantage are still fairly high.

3. Work significantly reducing the resources required for a quantum computer to reach quantum advantage for an already established algorithm/application.

Example 1: improved chemistry algorithms (arXiv:2011.03494) with application to simulating the FeMoCo nitrogen fixation catalyst. Submission would be stronger if the magnitude of the resource reduction and thought delta were larger.

Example 2: improved algorithms for topological data analysis (arXiv:2209.13581 and arXiv:2209.12887). A significant weakness is that neither paper identifies real-world occurrences of the problem where quantum advantage is viable.

Impact Goal

Quantum computing has a disruptive potential for scientific discovery, which could translate into major gains for social good, but there are many technological and structural hurdles. XPRIZE Quantum Applications will challenge innovators to develop methods for leveraging quantum computing to solve urgent global challenges. The competition is designed to help us realize a future in which widely accessible, powerful quantum computing resources are used to unlock a plethora of new technologies and innovations that will benefit humanity.

Objectives of the Competition

- Incentivize the existing community of quantum information scientists more towards concrete and practical considerations of how to best deploy quantum algorithms to solve real-world problems, the resources required to realize quantum advantage, and the impact and challenges associated with deploying those applications.
- Expand the cohort of engineers, scientists, and application specialists focused on quantum computing.
- Motivate increased quantum computing activity and initiatives in diverse countries and regions (including lower- and middle-income countries) that have challenges in obtaining the resources and expertise needed for quantum.
- Motivate the design space for future quantum computers and how they should be used, helping to expand the landscape of proposed technologies, compilation strategies, error-correction and mitigation protocols, and other implementation choices.
- Improve methodologies for evaluating quantum computing applications and their associated impact.
- Shape the development of quantum technology for the creation of social good and/or increase the number of sustainability-relevant quantum use cases.
- Inspire policymakers to facilitate major advancements in quantum computing that are equitable, with access and benefits that are widely distributed as possible.
- Produce tangible progress for applied quantum computing that will counteract both hype and skepticism.

Competition Structure

A major challenge for quantum information science is to scale up the hardware to thousands or millions of physical qubits with high fidelity operations and to realize fault-tolerant logical qubits. Theoretical challenges, including the development of better schemes for quantum error-correction and new quantum algorithms and applications, will be critical for the impact of this technology. There are some ideas about the most promising opportunities for applications, but we don't know where the first demonstrable, truly disruptive algorithm for a real-world problem will come from. We hope that a fault-tolerant quantum computer will have applications that we cannot imagine today – just as when the first transistor was made in the mid-20th century, no one predicted that it would ultimately lead to laptops and smart devices. Therefore, the competition is structured as a **"largest advance" competition** with **problem and contribution-type flexibility** across beneficial applications to allow teams to discover unexpected opportunities and feed the bank of use cases.

Registration

Interested teams are required to register for the competition in the Prize Operations Platform and share a brief overview of their concept with the community (see Registration Process).

Teams will be allowed to join at wildcard junctures as the landscape of QC players develops over the 3 year competition. Wild card rounds will be opened ahead of judging in Phase I and II to allow new teams with groundbreaking ideas to enter the competition. Dates and procedures for wild card entrants will be communicated ahead of time in the Rules & Regulations for each competition phase. The XPRIZE operations team might consider additional wild card rounds, in consultation with advisors. These applicants will need to demonstrate their ability to meet or exceed the current competition pool as determined by our judging panel.

Teams may update or entirely pivot the focus of their submission up until the Phase I submission deadline (see Competition Calendar for more detail). Any major redirection following Phase I judging would need to be re-entered as a wildcard submission.

Two Phases

Two technical submission phases over 3 years will bridge abstract ideas into concrete steps to implement powerful algorithms of the future.

- Phase I: Teams will submit a paper detailing the socially beneficial application they aim to solve with quantum computation and why it is important to solve this problem, asymptotic analysis of the quantum advantage of the application, and the overall novelty of the proposed approach. Teams will be assessed and ranked based on their submissions. Up to 20 teams will share a $1 million prize purse and advance to Phase II.

- Phase II: Teams will submit an analysis to quantify the real world impact of solving their defined problem, performance benchmarking against the best known classical solution, and compilation of their algorithm to realistic models of hardware and/or quantum error-correction to perform finite resource estimations for solving real-world instances of their problem with a meaningful quantum advantage. Teams will be evaluated and ranked according to the criteria for these judging categories, with a single or multiple Grand Prize Winner(s) splitting a pot of $3 million and some number of runner-ups (according to the discretion of the judges) splitting an additional $1 million.

XPRIZE will host informational sessions and facilitate team meetings, and may suggest (but not compel) that teams merge to form a more robust or interdisciplinary team. These sessions will allow teams to get to know each other and receive important Competition updates. All teams are encouraged to join, but participation in these sessions is not mandatory. There is a talent gap overall in the quantum field, and particular types of expertise that will be required for the Phase II competition can be particularly rare. Therefore, **competitors will be offered support** to translate their Phase I work to Phase II, including access to compilation & resource estimation experts, tools, and impact consultants as needed.

Prize Purse

The $5M prize purse will be distributed as follows:

After 24 months of competition, the judges will review all whitepaper submissions and equally distribute Milestone Prizes from $1 million to up to 20 semi-finalist winners. At the discretion of the judges, these awards may be granted on a conditional basis, subject to the team's demonstrated commitment to continuing to develop and advance their solutions and to compete for the Grand Prize. Teams that do not receive or do not compete for Milestone Prizes may still be eligible to compete for the Grand Prizes, at the discretion of the judges.

After 36 months, judges will select the Competition winners:
- $3 million split among up to three Grand Prize Winner(s)
- $1 million split between two and five Finals Runner-ups (at the discretion of the judges; e.g., if two Finals Runner-ups selected then each would receive $500k).

Each team must specify a legal entity (i.e., individual or corporation). After being named a winner by the judges, XPRIZE will pay the award to the specified legal entity. ***Prize winners can receive and use the award money however they wish.***

Competition Calendar

The active competition takes place in two phases over 3 years:

- Phase I: Semifinal Submission, Judging, and Milestone Payments (24 months)
- Phase II: Final Submission, Judging, and Grand Prize Award (12 months)

Competition registration opens in Q1 2024. Registration for the prize will remain open through June 2024. Prize guidelines will be published simultaneous to the registration opening and a public comment period will be run through Spring 2024.

Table 1: Competition Calendar - Phases I and II

PHASE ONE: SEMIFINALS	
• "Soft-launch" announcement of prize and public comment opens	Jan 2024
• Registration opens	Mar 2024
• Registration closes	June 2024
• **Registered Teams** develop technical proposals	Mar 2024-Oct 2025
○ Teams will be asked to provide one interim report on progress	
• Phase I Submission Deadline	Nov 2025
• Phase I Judging	Nov 2025-Jan 2026
○ *The judging panel can allow up to 20* ***Semifinalist Teams*** *to advance to the Finals Round*	
• Milestone Payments Awarded to Top Submissions	Feb 2026

PHASE TWO: FINALS	
• **Finalist Teams** Confirmed	Mar 2026
• Phase II Submission Deadline	Oct 2026
• Phase II Submission Judging	Oct-Dec 2026
• Grand Prize Winner & Runner-up Announcement	Jan 2027

Impact and scaling work begins at Finalist down select and runs 12-18 months beyond final award.

Eligibility

XPRIZE believes that solutions can come from anyone, anywhere: Scientists, engineers, academics, entrepreneurs, and other innovators from all over the world are invited to form a team and register to compete.

Any person or entity can participate in the Competition, no matter their citizenship or nationality, as long as they are not organized or ordinarily resident at the time of participation in Cuba, Iran, North Korea, Syria, or the Crimea region of Ukraine (or where otherwise prohibited by U.S. law – See Sanctions Programs and Country Information | US Department of the Treasury). If a Team does have a Team Member who is ordinarily resident in such destinations, it will be up to the team to obtain a license of authorization issued under U.S. Law.

While global in focus, the competition will be conducted in English. All teams must be prepared to communicate with XPRIZE and make their submissions in English.

Registration Process

To participate, a team is required to first create an account in the Prize Operations Platform (POP) . POP is an online platform through which teams will register for the competition, pay a Registration Fee (see Registration Fee) , and submit important documents throughout the competition. All teams must appoint a Team Leader, who will be responsible for maintaining communications with XPRIZE.

To remain eligible to compete, teams must complete the Registration Submission Form, submit a Competitor Agreement, and pay the Registration Fee. Teams are expected to maintain their POP profiles throughout the competition, ensuring their profile is up to date with the most recent team information, including an active email address.

Multiple entries by a single team: One group may choose to submit multiple solution entries to the competition. In this case, each entry must be registered as a separate Team, complete with its own team profile, description, and entry fee in the POP.

Teams are encouraged to collaborate and share skills. A team may recruit additional experts and can add new members to their team at any time throughout the competition. Teams may also merge with other teams during the competition. Teams must notify XPRIZE of a merger before it takes place. In the case of mergers, teams must register under one legal entity and assign one team leader.

Registration Submission Form

Each team will complete a registration form. The registration submission form activity will be assigned to teams in POP automatically upon creating a team profile. The form will ask about the following: (1) Team composition, i.e., number of expected team members; (2) Proposed solution focus areas; (3) Any areas of technical or subject matter expertise your team is seeking support for; (4) Whether your team is open to collaboration opportunities.

The registration submission will be used to obtain an initial landscape of competitors, and to support the facilitation of collaboration opportunities between teams. The aggregate information from these submissions may be shared to support team collaboration opportunities. The XPRIZE Quantum Applications Operations Team will not distribute specific details about any team without permission.

Competitor Agreement

To be considered to advance to subsequent stages of the Competition, all **Registered Teams** are required to sign the Competitor Agreement to acknowledge the terms expected of teams upon entering the Competition. The Competitor Agreement is a contractual document that contains vital information detailing the requirements teams must meet to remain eligible for the Competition. Competitor Agreements will be reviewed and signed when a team makes their registration fee payment. Teams are encouraged to thoroughly review the Competitor Agreement before signing.

Registration Fee

Creating a POP account is free. Once the account is created, a registration of $50 will be required. All fees collected go toward supporting post-prize efforts, including Alumni Network development and prize impact work. We understand that entering an XPRIZE competition can present a significant commitment of time and resources, and so we provide discounts for early registration, registration fee waivers for otherwise qualified teams, and opportunities to join the competition after the initial registration period.

Oversight & Judging

To win the prize, teams must develop a new (or meaningfully improved) application of quantum computers that addresses a computationally complex problem and demonstrate the viability of the proposed quantum algorithm for this task, establishing a clear practical quantum advantage over classical methods with a compelling case for positive societal impact.

The openness of the competition across a range of socially beneficial application areas will create complexity for the judging process and potentially introduce challenges. Additionally, both quantum and classical computing are constantly evolving; thus, the classical benchmarking goal posts or state-of-the-art techniques for compiling quantum algorithms or mitigating or correcting errors could potentially move during the competition. Therefore, an expert Advisory Board, along with a diverse, qualified Judging Panel and methods for standardization of the process (i.e., a judging rubric and standard tools) will be essential to the judging procedures and oversight of the competition.

Certain judging criteria will be more or less emphasized across Phase I and Phase II judging, due to the different submission requirements (see Submission Requirements for Judging). Therefore, the judging panel will be tailored somewhat between the competition phases so the overall composition of the panel members can provide the categories of expertise needed to thoroughly evaluate submissions. For example, a more complete evaluation of application impact will occur in Phase II, so judges with domain expertise relevant to the submissions will need to be empaneled between Phase I and Phase II.

Judging Criteria

Once again, the winning submissions will most accelerate the field of quantum algorithms towards quantum advantage for positive real-world applications. In determining this, our judging panel will weigh a number of factors including most prominently:

A. The projected magnitude of positive real-world impact that would result from quantum advantage in the proposed application area(s).
B. The estimated quantum resources required for quantum advantage (i.e., how near-term?).
C. The strength of the evidence supporting claims for (A) and (B).
D. The novelty of the submission (i.e., magnitude of the "thought delta" introduced).

Thus, we expect that most submissions will address the following.

Problem Statement & Scope: The team has chosen a challenging and socially beneficial application with significant global impact to tackle. (*Phase I*)

Impact on the Problem Area: The team has made the case that the solution they are proposing would create a positive impact in the real world (*Phase I*). The team has established with high confidence that their solution would lead to significant positive impact if implemented (*Phase II*).

Asymptotic Speedup: The team has convincingly demonstrated a favorable scaling advantage the quantum computation would have relative to classical (*Phase I*). Note that ultimately it is just important that a quantum computer solve the problem with some advantage relative to a classical computer; however, our expectation is that at least a quadratic speedup will be required to reach quantum advantage to reasonable problem sizes due to the high overheads of error-correction *(for more on this topic, see [Google paper, Microsoft paper])*.

Classical Benchmarking: The team has shown the numerical performance advantage the quantum algorithm delivers for particular input data over the best known classical computation (*Phase II*). In some cases (especially in quantum simulation) it might also be important to provide evidence that the target quantities are not readily measurable from other laboratory experiments.

Viability: The team has provided evidence the algorithm could be run on future fault-tolerant hardware OR the team has demonstrated the algorithm can run within a coherence time and circuit depth that is convincingly argued to be achievable on a NISQ architecture or analog quantum simulator. The timeline for implementation and proposed impact will be qualitatively assessed by the judges (*Phase II*). Ultimately, it is up to the teams to perform an analysis of the viability of their algorithm making assumptions they argue to be reasonable on matters such as connectivity, gate type, cycle time, etc. *Very roughly*, we imagine the most compelling NISQ algorithms would require fewer than 1e4 two-qubit gates and fault-tolerant algorithms would require fewer than 1e13 logical T gates to reach quantum advantage. Of course, a fault-tolerant algorithm with even fewer T gates would be better assessed as even more viable and thus have a lower bar for impact. However, we also understand that (particularly for complex new algorithms) it might take additional years of work to further reduce resource counts and so will also keep an open mind about algorithms requiring even more resources, if the algorithmic approach is relatively new and the promised impact is large.

Novelty: The approach is novel and superior within the chosen problem area when compared to established and ongoing efforts (*Phase I*).

Again, we expect that competitive submissions will make at least one of the following types of contributions (we also give a few examples from the last five years; however, note that these examples are not in any way an expression of preferred areas of focus):

1. A new quantum algorithm for solving a new class of problems with quantum advantage.

   Example: quartic quantum speedup for tensor principal component analysis (arXiv: 1907.12724). Submission would be incomplete without suggesting a target real-world application and submission would be much stronger with some estimated resources for quantum advantage. Still, significant points for novelty.

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Example 2: improved algorithms for topological data analysis (arXiv:2209.13581 and arXiv:2209.12887). A significant weakness is that neither paper identifies real-world occurrences of the problem where quantum advantage is viable.

Submissions Out of Scope for the Prize

- Applications that use quantum technology without quantum computation as a component
- Contributions that are exclusively refining quantum error-correction protocols without focusing on at least one real-world applications
- Quantum-inspired classical algorithms
- Applications that cannot reasonably make a claim of overall societal good (please see Appendix B "Social Good Definition & Frameworks" for recommended definitions and frameworks)
- Work that was published or submitted to a preprint repository before the Competition start date. Note that one can certainly build on past work (this is expected) but only content authored by the submitting team that was not public prior to the competition start date will be considered as part of the advance/contribution to be assessed.

**Note: for this submission type to be competitive for Phase I judging, competing teams will need to provide additional information in their Phase I submission beyond what is described in Table 2: Submission Requirements for judges to make a complete determination for milestone award and advancement to Phase II. Additional guidance will be provided well ahead of the Phase I submission deadline in the official Rules & Regulations and other official prize documentation.*

Submission Requirements For Judging

XPRIZE will provide submission templates and additional guidance in advance of each submission deadline, including detailed instructions on how to complete and upload the submission.

Table 2: Submission Requirements

	PHASE I REQUIREMENTS	PHASE II REQUIREMENTS
1. Problem Statement & Scope	Provide a detailed description of the problem (or related problems) that one is proposing to solve using quantum computation: a. Provide descriptions of the problem (both general and specific forms) stated as concise and formal computer science problems. b. State the relevance of the problem to an application that would benefit society in some way (e.g., one or more of the UN SDGs). *Notes:* *(a) Submissions that develop new quantum methods that apply to a broad set of problems are potentially seen as more valuable than those that only solve one very specific problem. For example, one might develop a general approach to solving linear differential equations with an exponential speedup and that would be seen as more impactful than an approach that only solves second order parabolic differential equations with an exponential speedup. Nonetheless, in that situation one should still also give specific examples of applications such as (in this fictional example) using that differential equation solver to better solve the mechanical wave equation so that acoustic scattering simulations can assist with geological surveys in a way that would better enable earthquake prediction.*	***NA***

	PHASE I REQUIREMENTS	PHASE II REQUIREMENTS
2. Impact on the Problem Area	Make the case that a quantum-enabled solution to the problem stated in **(1) Problem Statement & Scope** would change our world for the better: a. Provide arguments that the specific computational problem being posed is actually, in fact, a bottleneck or a particular challenge that is obstructing progress towards a socially beneficial application. b. Put forward data and arguments that detail how a solution to this problem will make a real world difference. Notes: *Judges will weigh the potential value of the application against the perceived likelihood (influenced by the strength of arguments in the submission) that the application will actually be unlocked by the proposed quantum computation.*	Quantify the change the solution might enable; to the extent possible, evaluate for key metrics that reflect the real world cost-benefit considerations of that change. Ideally, submissions are as specific as possible about how the quantum computation will actually contribute to bringing about real-world change. Notes: *For example, if proposing to use quantum simulation to develop better catalysts for Nitrogen fixation, estimate how much energy might be saved from more efficient processes, the effect on greenhouse emissions, and how cheaper fertilizer would impact agricultural output and food security, including deaths from hunger and related causes.* *Predictions of impact should be validated by an expert in the application area; XPRIZE can introduce participants in Phase 2 to researchers, consultants, and impacted communities who can help make the full case for application impact.*

	PHASE I REQUIREMENTS	PHASE II REQUIREMENTS
3. Quantum Advantage	Make a clear case as to what sort of quantum advantage the quantum computer is expected to have relative to classical computers. a. State the asymptotic runtime of the quantum algorithm in terms of gate complexity (circuit size) and space complexity (number of qubits). b. Make an earnest attempt to quantify the computational resources of the best classical algorithms and relate that to the overall quantum speedup. c. Provide information about all relevant system parameters impacting performance (e.g., any required approximations). *Notes:* *(a) The most ideal thing would be to rigorously prove the exact scaling of the quantum algorithm. However, in some cases submissions might rely on numerical or heuristic evidence to bound certain errors or the number of times a subroutine must be applied, etc. While that is potentially acceptable, the submission will be judged in part on the strength of the evidence for the stated scaling. For example, if numerics can be computed up to problem relevant sizes or short of that but with very compelling numerical trends, it will be seen as a stronger result than if the numerical evidence goes up to twenty qubits with an unconvincing trend. If the asymptotic scaling depends on a mathematical conjecture that is widely believed to be true (albeit difficult to prove) then that would be stronger evidence than if the scaling is argued in a handwavy fashion.* *(b) Examples of the strongest sort of evidence here would be to show a problem is BQP-Complete, to lower bound the classical runtime as something unfavorable using information theoretic techniques (e.g., to show a relativized exponential speedup in a closely related oracular version of the problem) or for the best classical algorithms for the problem to be well studied for many years without producing any algorithms that scale nearly as well as the best quantum algorithms (e.g., the case with prime factoring). However, such strong results will not always be possible. In that case the classical complexity might need to be estimated from numerical implementations that are argued by the participants to be state-of-the-art. If there is little classical literature on solving or approximating the problem then it raises the question of how important is this problem, really? However, in those cases one should also attempt to develop their own classical algorithms that leverage the same sort of structure that is exploited by the quantum algorithms. We note that if quantum algorithms are developed that give less than a quadratic speedup then it will be seen as unlikely that such speedups will translate to real-world advantage on error-corrected quantum computers (for more on this topic, see [Google paper, Microsoft paper]). Submissions suggesting that practical*	*NA*

	quantum advantage without a super-quadratic speedup are viable in the near-term will need to make an exceptionally compelling case as well. Ultimately, the quantum advantage proposed in the submission might not fit cleanly into the framework anticipated here. In that case, what is most important is to explain what sort of quantum advantage is expected, and to provide the strongest possible scientific evidence for its existence. *(c) For example: If approximations are required (or an approximation ratio is the goal) then quantum advantage should be quantified in terms of not just problem size but approximation parameters. For example, in quantum simulation it would be helpful to quantify runtime in terms of parameters such as basis size, system size, error tolerance, evolution time, and relevant dimensionless ratios such as t/u in the Hubbard model. Super-quadratic speedups in any problem parameters are seen favorably.*	

	PHASE I REQUIREMENTS	PHASE II REQUIREMENTS
4. Classical Benchmarking	***NA***	Make an earnest attempt to define the constant factors associated with solving the problem on classical computers. *<u>Note:</u>*

		Ideally, this would involve deploying state-of-the-art implementations of the best classical codes on HPC resources to extrapolate what would be required to solve target instances of the application. Such benchmarking will also be useful in pinpointing exactly what problem sizes would be required to transition into the regime of quantum advantage. *The importance of classical benchmarking is somewhat relative to how close a competition there is to the quantum approach. For example, the classical approaches to factoring are sufficiently inefficient that one does not really need to run a state-of-the-art factoring code to argue that 2k bit RSA encryption is classically intractable. On the other hand, if the quantum algorithm proposed has only a quartic speedup then classical algorithms might be much more competitive and it will be more important to determine precisely how the classical competition performs. Note that there are almost always at least approximation algorithms classically and so if the proposal is to solve a problem exactly with a large speedup then one must devote considerable effort (and probably, numerical calculations and benchmarking) to make the argument that classical approximations are insufficient for the application (e.g., in chemistry, one should probably do some classical calculations that diagnose the failure of tractable classical methods such as DMRG, etc.).*

	PHASE I REQUIREMENTS	PHASE II REQUIREMENTS
5. Viability	***NA***	Describe what quantum resources will be required to realize a meaningful impact on their proposed application: a. Argue at what problem sizes quantum computers will have a real world impact. This should take into account both the constant factors and scaling of what is required for practical quantum advantage relative to classical algorithms, but also the demands of the real world problem. b. Compile the quantum algorithm to a realistic architecture with enough detail to assess the leading order constant factors. Estimate how many circuit repetitions are required in addition to merely saying how many gates are required in each realization of a circuit. ***Submissions related to new NISQ applications have additional considerations.**** c. Impact is measured (and discounted) against the projected timeline to implement the solution.

Notes:

(a) For example: It is not enough to show that one can simulate FeMoCo (a catalyst for Nitrogen fixation) in a basis size that would be classically intractable. One should also make an argument for exactly what basis size is large enough to resolve the relevant chemical questions that impede our understanding of that system.

(b) For example: If one is proposing an application that would require a quantum error-correcting code whose execution is bottlenecked by non-Clifford gates then one should count the leading order number of T or Toffoli gates in the algorithm, as well as the total number of logical qubits. And perhaps one should argue that this cost model is appropriate (e.g., if the Clifford complexity is multiple powers of the problem size larger than the Toffoli complexity, that would be cause for concern). It would also be helpful to give some examples of how many physical qubits and how much runtime might be required to realize the algorithm within a set of assumptions about an error-corrected quantum computer in a particular architecture (however, this is relatively less important as different participants might choose different assumptions and so it is easier to compare T/Toffoli complexities + logical qubit count)

(c) An important principle of the competition will be the discounting of impact against time. For example, if an application could be realized in 3 years it would be much more impactful than if the same application could be realized in 10 years. The principle is a "time value of impact", similar to the "time value of money". If an application can help people today it will improve the world more than if it can help people tomorrow. However, submissions that argue for a particularly large and important impact can still be competitive even if many resources and a large fault-tolerant device are required.

***Note for NISQ algorithm submissions**

In the case of a NISQ application submission, competitors must include the following:

- *The constant factors of how many physical qubits, gate depth, number of circuit repetitions, and gate complexity is required* ***based on a specific NISQ architecture*** *(e.g., superconducting, ion trap, neutral atoms).*
    - *One should attempt to argue how realistic those requirements are by comparing the requirements to capabilities already demonstrated in prior NISQ experiments on those architectures. For example, experiments that require an order of magnitude better gate fidelities (or an order of magnitude more coherence time) than existing platforms might be seen favorably whereas those requiring multiple orders of magnitude more of such resources will be seen as less realistic and would likely do better to instead (or additionally) compile to error-correction architectures. The same also pertains to the problem sizes on which hardware platforms have managed to realize the required fidelities and coherence times (e.g., having a really good two qubit gate on 4 qubits is not going to be persuasive evidence of anything relevant to an application).*
- *Schemes for error-mitigation and arguments about their effectiveness.*

	PHASE I REQUIREMENTS	PHASE II REQUIREMENTS
6. Novelty	Submissions will be assessed for overall novelty and the relative “thought delta” introduced by this work. *Notes:* *It is not necessary that an entirely new framework for quantum algorithms is developed. For example, one might find a great real-world application of the HHL algorithm or quantum abelian hidden subgroup algorithm and if the case is made that those approaches could solve a previously unknown application and the case is made that the speedup is large, such a submission would be seen very favorably. However, the overall novelty of the approach does matter. Submissions that introduce new concepts in the service of connecting quantum algorithms to applications, or submissions that introduce fundamentally new quantum algorithms, will be seen more favorably. If a submission opens up an entirely new area of quantum algorithms and applications research that will be seen more favorably than submissions that only apply to a very specific problem or simply change the way we approach applications that are already known to be in scope for quantum computers.* *Sufficiently well argued applications of quantum simulation are very much in scope. However, as methods for quantum simulation are generally well established and some real-world applications are already known, for such submissions the bar for all other categories (viability, specificity, impact, quantum speedup, etc.) will essentially be higher than submissions that develop new concepts.*	*NA*

	What is relatively less important is novelty in methods of establishing classical limitations or the quantum scaling. For example, it is nice if one has a very cool new proof technique (perhaps of broad applicability) that is able to establish that a problem is BQP-Complete or lower bound a classical method. But the novelty of proof methods will not particularly help a submission beyond establishing the extent to which this problem is hard classically. Likewise, if one develops a new compilation technique that leads to the approach having lower constant factors, that may be valuable but it probably won't help the chances of the submission beyond its utility in showing that the application is more viable.	

Judging Platform & Tools

Phase I and II submissions will be subject to review by select members of the Judging Panel. Judges will be able to rank their preference to review specific submissions based on their expertise. An automatic exclusion mechanism will be employed for strong conflicts of interest (e.g., faculty in the same academic department), along with a disclosure-based system for judges to opt out of submissions they flag a standard conflict of interest with. Final review assignments will be made by the Judging Panel Chair. Three judges will be assigned to each submission.

Judges will review and rank their assigned submissions using an electronic platform, followed by an open comment and discussion period. Official decisions made by the Judging Panel will be approved by a majority of the Judges that vote on each submission after careful and impartial consideration of the testing protocols, procedures, guidelines, rules, regulations, criteria, results, and scores set forth in the Competitor Agreement, these Competition Guidelines, Rules and Regulations, and all other applicable exhibits to the Competitor Agreement. If any vote of the Judges results in a tie, then the Judging Panel shall determine, in its sole and absolute discretion, the mechanism to settle the tie. Similarly, if one or more teams are tied at any stage during the competition, the Judging Panel shall have the sole and absolute discretion to settle the tie.

Decisions of Judging Panel are Final

The Judging Panel shall have sole and absolute discretion: (i) to allocate duties among the Judges; (ii) to determine the degree of accuracy and error rate that is acceptable to the Judging Panel for all competition calculations, measurements, and results, where not specified in the Rules and Regulations; (iii) to determine the methodology used by the Judging Panel to render its decisions; (iv) to declare the winners of the competition; and (v) to award the prize purses and other awards. Decisions of the Judging Panel shall be binding on XPRIZE, teams, and each team member. XPRIZE and teams agree not to dispute any decision or ruling of the Judging Panel, including decisions regarding the degree of accuracy or error rate of any competition calculations, measurements, and results. Teams shall have no right to observe other teams' testing or evaluation, or to be informed of other teams' calculations, measurements, and results, unless such information is made publicly available by XPRIZE, or by a team choosing to release their own data publicly.

Roles & Responsibilities

Competing Teams

1. **Good Standing**: Teams must register their intent to compete on the XPRIZE Prize Operations Portal (POP), sign the Competitor Agreement, and pay the registration fee ahead of the deadline in order to be eligible for an award. Teams must complete all required activities as outlined in the Competitor Agreement, Competition Guidelines, Rules & Regulations, and other official documents throughout the duration of the Competition.

2. **Fundraising**: All costs of competing in The Google Quantum AI XPRIZE for Quantum Applications are the responsibility of the competing team.

3. **Safe and Ethical Behavior**: Teams are responsible for maintaining the health and safety of their teams and the environment over the course of their participation in the prize. Teams must comply with all laws and regulations which apply to their participation in the prize. XPRIZE reserves the right to expel teams who do not uphold reasonable standards of safety and ethics.

Advisory Board

1. **Selection of Advisors**: XPRIZE and its Partners and Sponsors will collaborate to appoint a panel of subject matter experts, and big-picture thought leaders to serve as the Advisory Board for the competition. The Advisory Board will remain in place throughout the competition to advise XPRIZE regarding the scientific, economic, social, and other elements of the competition.

2. **Independence**: The Advisory Board will be independent of XPRIZE, and all teams and team members. No Advisor, nor any member of the Advisor's immediate family, shall participate, nor have any financial or other material interest, in XPRIZE, and/or any team or team member. All members of the Advisory Board shall promptly disclose to XPRIZE any such current, former, or expected future conflict of interest with XPRIZE, the Title Sponsor, or any team or team member.

3. **Role of Advisory Board**: The duties and responsibilities of the Advisory Board may include, but not be limited to: (i) assisting with the establishment of qualifications for prospective Judges; (ii) recommending members of the Judging Panel; (iii) assisting with development of testing protocols and judging criteria; (iv) and providing input toward the development of these Competition Guidelines.

Judging Panel

1. **Selection Of Judges**: A Judging Panel selected collaboratively by XPRIZE and advisors to the competition will be convened that represents diverse quantum and domain-relevant expertise to account for the openness of the competition (e.g., SDG problems, application areas) - the competition's testing and judging process is crucial to ensuring robust standards, objectivity, and fairness. The following categories of expertise will be represented on the Judging Panel:
    - Quantum Algorithms
    - Resource Estimation & Compilation
    - Error Correction
    - Classical Benchmarking
    - Expertise in the Use Case Domains

2. **Independence**: The Judging Panel will be independent of XPRIZE, and all teams and team members. No Judge, nor any member of Judge's immediate family, shall participate, nor have any financial or other material interest, in XPRIZE, and/or any team or team member. All members of the Judging Panel shall promptly disclose to XPRIZE any such current, former, or expected future conflict of interest with XPRIZE, the sponsor, and/or any team or team member.

3. **Role Of Judging Panel:** The duties and responsibilities of the Judging Panel will include, but not be limited to: (i) evaluating teams' compliance with the Competitor Agreement as they relate to prize operations, these Competition Guidelines, and the Rules and Regulations for the purposes of the competition; and (ii) the awarding of points and selection of teams that will proceed to each subsequent round of the Competition.

Intellectual Property

As of the date of submission, each Team must own, or hold appropriate license rights to, all technologies, methods, resources, and Intellectual Property included in its submission. Teams will retain ownership of the Intellectual Property they bring to the Competition, and which they develop as part of their Competition entry.

All details relating to team technology, innovations, or methods provided in submissions to XPRIZE at the submission deadlines will remain strictly confidential. However, teams will be required to communicate about their submissions in some format publicly (e.g., arXiv) after the judging and award phases to advance the field. Please refer to the Competitor Agreement for more details.

Appendix A: Glossary

Interested Team: A team or individual that is interested in participating in the Competition and has created a profile in the XPRIZE POP system.

Registered Team: A team that has paid the required registration fee, signed the Competitor Agreement, and is eligible to compete.

Semifinalist Team: A team that has provided a Phase I submission for Judging.

Finalist Team: A team that has successfully completed Semifinals Judging and is approved by the Judging Panel to provide a Phase II Submission for Judging.

A more complete Glossary will be available in the official Competition Guidelines published at the start of competition.

Appendix B: Experts List

We express immense gratitude to the distinguished panel of experts whose invaluable insights and expertise were instrumental in shaping the comprehensive guidelines for the XPRIZE Quantum Applications competition. This group will have critical involvement throughout the competition as members of our Advisory Board and Judging Panel.

NAME	LAST NAME	TITLE	AFFILIATION
Amira	Abbas	Postdoctoral Researcher	University of Amsterdam
Dorit	Aharanov	Professor	Hebrew University
Ryan	Babbush	Head of Quantum Algorithms	Google Quantum AI
Andrew	Baczewski	Principal Member of Technical Staff	Sandia
Dominic	Berry	Professor	Macquarie University
Sergio	Boixo	Principal Scientist, Quantum Computing	Google
Fernando	Brandao	Director, Quantum Applications	Amazon
Earl	Campbell	VP of Quantum Science	Riverlane
Di	Fang	Assistant Professor of Mathematics	Duke University
Craig	Gidney	Quantum Software Engineer	Google Quantum AI
Christian	Gogolin	Head of High Performance & Quantum Computing	Covestro Deutschland AG
Guang Hao	Low	Principal Researcher	Microsoft
Brigitte	Hoyer Gosselink	Director, Product Impact	Google.org
Stephen	Jordan	Senior Staff Scientist	Google Quantum AI
Helmut	Katzgrabber	Global Practice Lead – Quantum	Amazon
Shelby	Kimmel	Assistant Professor	Department of Computer Science, Middlebury College
Joonho	Lee	Assistant Professor	Harvard
Catherine	Lefebvre	Vice President Global Policy & Partnerships; Senior Advisor	PASQAL; Open Quantum Institute (GESDA)
Hartmut	Neven	Vice President of Engineering	Google
Naomi	Nickerson	VP of Quantum Architecture	PsiQuantum

John	Preskill	Richard P. Feynman Professor of Theoretical Physics	Caltech
Barry	Sanders	Professor	University of Calgary
Norbert	Schuch	Professor	University of Vienna
Maria	Schuld	Quantum Machine Learning Research Lead	Xanadu
Barbara M.	Terhal	Professor	Delft University of Technology
Matthias	Troyer	Technical Fellow & CVP; Co-Chair of the Quantum Task Force. For Microsoft	Microsoft Quantum; GESDA
Will	Zeng	Partner	Quantonation and Unitary Fund

Appendix C: Social Good Definition & Frameworks

In an era where technology profoundly impacts society, quantum information science has potential to emerge as a force to drive progress for global social good and sustainability. Social good, in this context, refers to initiatives and technologies that yield significant, positive impacts on large groups or entire societies.

This competition is committed to fostering innovations that contribute to societal well-being and there are some clear examples of application areas that are not consistent with promoting social good, including algorithms aimed at cryptography breaking, weapons development, and manipulation of financial markets.

Competing teams will be asked to make a compelling case that their solution, if implemented, would have a positive impact on society. However, the social impact of a technology is often complex and multi-faceted. It can have varying effects on different groups of people and may even bring unintended consequences. Assessing potential impacts requires consideration of diverse social, cultural, economic, and environmental contexts.

These challenges are counterbalanced by the unique opportunities that quantum technologies offer – this competition is an exciting venue to contribute to that exploration. Competing teams will be provided with resources and support, particularly in Phase II where judges will be looking for a complete case to be articulated for application impact.

Aligning technological advancements with social good frameworks is an important step to ensure that these developments are not only groundbreaking but also responsible and beneficial on a societal scale. Competitors might consider any framework to guide their submission, but should be prepared to provide a rigorous and comprehensive argument. Example Frameworks:

- **Sustainable Development Goals Alignmen**t: Sustainable development is one of the most pressing issues of our time. Sustainability means humanity's current needs are supported without compromising the needs of future generations – it is a concept motivated by environmental protection, economic prosperity, and social equity. A prime example of a framework guiding these efforts is the United Nations Sustainable Development Goals (UN SDGs). Comprising 17 interlinked goals, the UN SDGs serve as a global blueprint for achieving a more sustainable future by 2030. Submissions to the competition could target application areas in several of these goals, including Good Health & Wellbeing (Goal 3), Affordable and Clean Energy (Goal 7), Industry, Innovation, and Infrastructure (Goal 9), and Climate Action (Goal 13). You can learn more about the SDGs from the United Nations website: https://sdgs.un.org/goals and from Open Quantum Institute's SDG initiative: https://oqi.gesda.global/.

- **Social Cost-Benefit Analysis**: Social Cost-Benefit Analysis (SCBA) is an analytic approach that evaluates the potential impacts of a proposed policy, program, or technology on society as a whole. Unlike traditional economic assessments that primarily focus on monetary considerations, this methodology embraces a more comprehensive range of effects that include social, environmental, and economic aspects. Submissions to the competition might utilize SCBA to identify and quantify the proposed benefits and potential risks to society, as well as to discuss assumptions and uncertainties of their assertions.

Examples of applications are numerous. For example, many quantum simulations could be said to help with the development of energy technologies. This could include simulations of high temperature superconductivity (which could help build mag-lev trains or lossless transmission lines), simulations of better materials for batteries or solar cells, modeling fusion reactors, etc. Also in scope would be quantum simulations for drug development, or more energy efficient or less toxic catalysts. Simulation of certain classical differential equations that pertain to mechanical engineering could potentially help with the UN SDG associated with infrastructure development. Topological data analysis could help with epidemiology. There are many possibilities. **Key for this contribution will be for submissions to try to be as specific as possible about how quantum advantage in a certain application would translate to a benefit for the real-world.**

Appendix D: Guidelines Change Log

Record of changes to the Guidelines document.

None