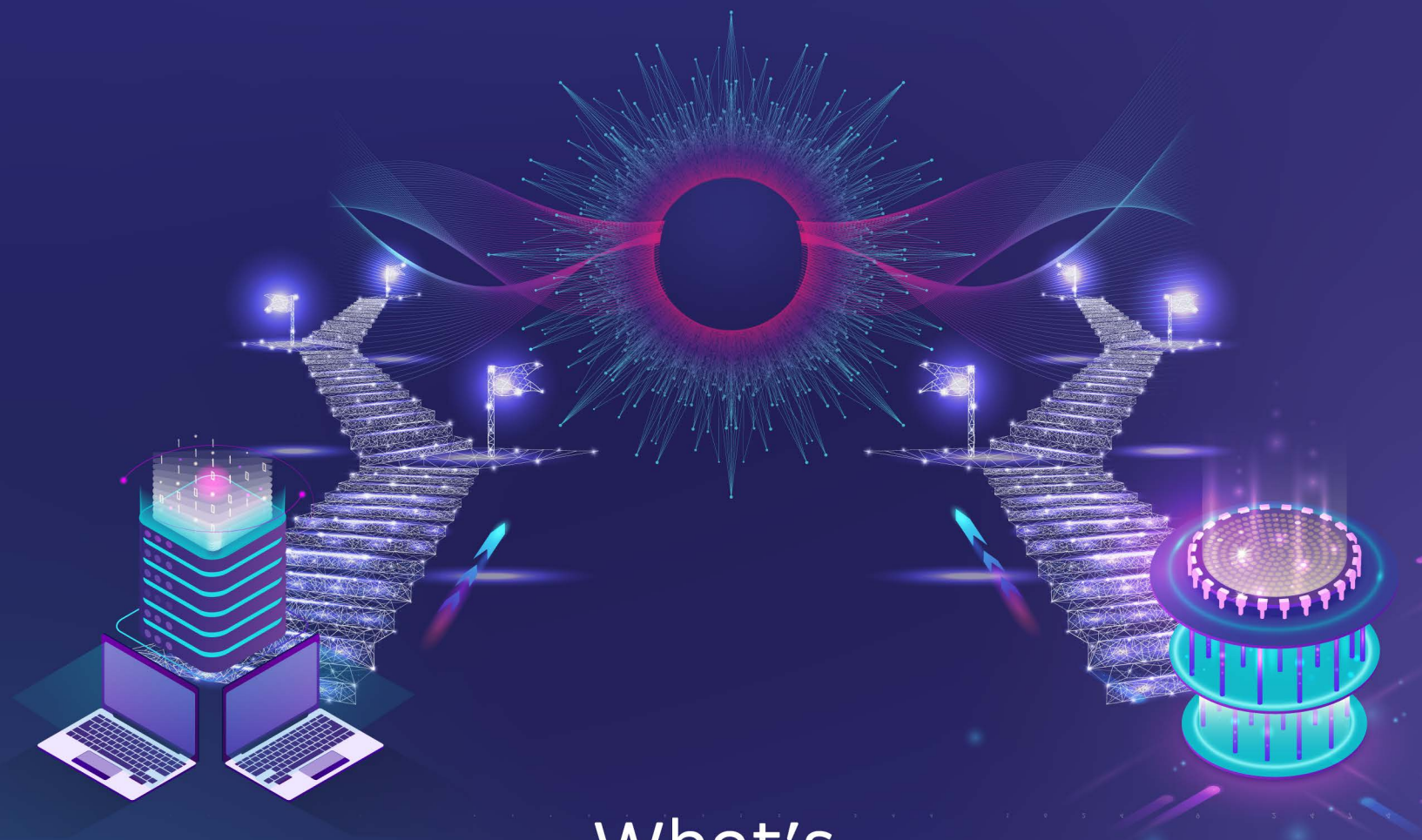


What's Your Best Path to Quantum?

QCi

Ready-to-run
Quantum Software

Quantum computing technology is advancing more rapidly than many experts expected.

Why?

The promise of quantum to solve extraordinarily complex business problems with advances in optimization, machine learning, and simulation has driven widespread interest, investment, and innovation.

Whether you believe it's five or twenty years before we have full use of quantum computers, the technology promises to be one of the most disruptive and valuable ever. Organizations who harness quantum power successfully will create significant competitive advantage as they transform their business, their industries and their markets.

As quantum technologies are advancing, companies are already preparing for quantum opportunities. Spending on quantum computing is projected to expand from $412 million in 2020 to $8.6 billion by 2027, according to IDC research.

It's time to pay attention.

What Does Quantum Mean to Your Business Today?

Early enterprise quantum applications will arrive in the coming years. Years may seem like a long time for planning.

Given the dramatic differences between quantum and classical hardware and software development, it's critical to start preparing your path to quantum, right now.

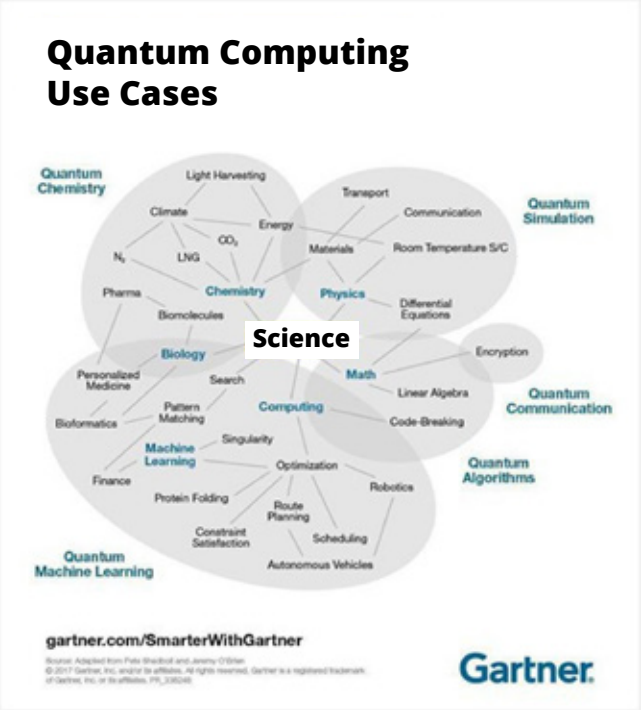
You'll need to develop a comprehensive quantum roadmap that covers both your business and IT strategy to deploy quantum innovation as quickly and as effectively as possible.

Most organizations exploring quantum computing have created small quantum innovation groups working in lab-like settings as they evaluate the gamut of potential new uses for quantum systems.

However, organizations that focus on identifying, evaluating and testing key opportunities in their current business applications will have a significant advantage when it comes to business readiness.

Quantum isn't just a cool new innovation. It's a platform for a whole new way of thinking about business and scientific problems. Preparing for practical use cases that drive business results is the goal, not experimenting with technology and algorithms for technology's sake. You also need to plan for both classical and hybrid quantum-ready systems in advance of pure quantum computing.

There are a wide range of use cases with potential benefits from quantum computing. The figure below shows Gartner's perspective on where quantum technologies will contribute.



Analysts expect quantum to begin delivering value to some business applications beginning in 2022 and 2023. For example, businesses with complex optimization challenges are expected to begin to adopt early hybrid systems, which blend processing from classical and quantum computers to better solve increasingly complex computations. Many also expect quantum computers will begin processing meaningful simulations of molecular structures for chemical, materials, and pharmaceutical companies. The arrival of quantum AI is farther out, as are applications that need more power such as prime factorization.

The figure below, from BSG, shares their perspectives on which applications will garner value from quantum computing

Exhibit 3 - The Value Creation Potential for Quantum Computing by Problem Type at Tech Maturity

	Applications	Value creation potential[1] ($B) Low	High
Cryptography ($40-$80B)	Encryption/decryption	$40	$80
Optimization ($100-$220B)	Aerospace: Flight route optimization	$20	$50
	Finance: Portfolio optimization	$20	$50
	Finance: Risk management	$10	$20
	Logistics: Vehicle routing/network optimization	$50	$100
Machine learning ($150-$220B)	Automotive: Automated vehicle, AI algorithms	$0	$10
	Finance: Fraud and money-laundering prevention	$20	$30
	High tech: Search and ads optimization	$50	$100
	Other: Varied AI applications	$80+	$80+
Simulation ($160-$330B)	Aerospace: Computational fluid dynamics	$10	$20
	Aerospace: Materials development	$10	$20
	Automotive: Computational fluid dynamics	$0	$10
	Automotive: Materials and structural design	$10	$15
	Chemistry: Catalyst and enzyme design	$20	$50
	Energy: Solar conversion	$10	$30
	Finance: Market simulation (e.g. derivatives pricing)	$20	$35
	High tech: Battery design	$20	$40
	Manufacturing: Materials design	$20	$30
	Pharma: Drug discovery and development	$40	$80

Sources: Academic research, industry interviews, BCG analysis.

[1]Represents value creation opportunity of mature technology.

If the analysts are right, and we believe they are, industries such as finance, travel, supply chain and logistics, global energy and materials, and advanced manufacturing will start reaping significant value from the hybrid classical/quantum approach in the early-to-mid 2020s.

The Urgency of Your Path 2 Quantum

Organizations in key industries must develop their strategic path-to-quantum roadmap now, if they don't want to be left behind.

Why the urgency? Because quantum is a new paradigm that takes years to comprehend and use. Waiting until it's ready for prime time sentences your business to significant competitive disadvantage.

For example:

Quantum computers are not one size fits all. Every quantum computer is based on slightly different hardware technology, including a **diverse array of qubits**. Your team needs to fully understand this diversity to create a roadmap that explores, tests, measures, and identifies the best hardware for each of your quantum use cases.

Quantum software has to be coded to run on a specific computer. Diverse hardware means diverse software requirements. Every program you create for quantum has to be coded at a low level to process on a specific hardware platform. Remember assembly code for devices? Think much more complex and sophisticated coding. Plus, every time you update or expand your QPU, you have to rewrite the code. That demands another level of expertise and effort from team members before you ever solve a problem, model, or simulation.

Only elite quantum experts can develop quantum software. Every program has to be coded from scratch, using complex, software development kits (SDKs) that demand deep quantum expertise. Quantum experts tell us it takes them over 9 months just to write their first program using SDKs. These resources are expensive and extremely difficult to find.

Quantum software requires tuning. Once a program is coded, it takes time and expertise to assure its running in the most efficient way. You can't just develop a program and assume it's complete. The tuning can take as long or longer than the 8-12 months it takes to code the program in the first place.

The above, and more, demonstrates the lengthy timeframe required before you ever even begin testing quantum options. Bottom line? You snooze, you lose.

What's the Best Path to Quantum for Your Business?

We are in the early stages of a very long learning curve when it comes to quantum technology. Every organization needs to begin to invest in exploring quantum computing, if they expect to remain competitive. According to the Quantum Daily, over 400 global companies already have quantum projects underway.

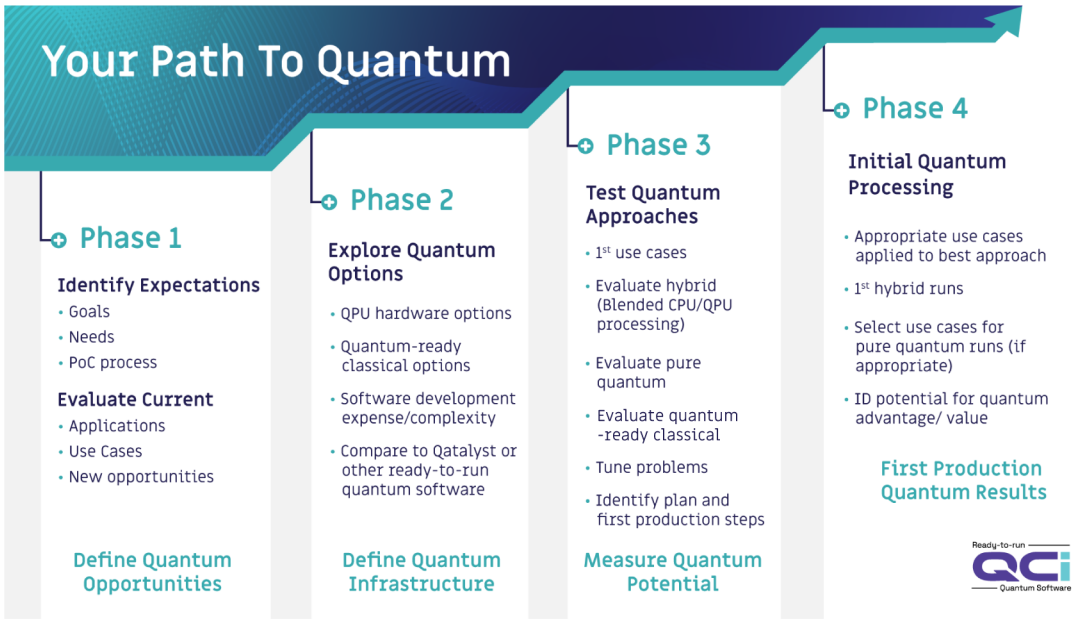
Where do you start? Especially given that quantum-skilled talent is in short supply, and it's unlikely that universities will be able to train enough quantum engineers to satisfy global needs in the near future. Plus, SDKs will change and evolve, programming and algorithm approaches will adapt, adding even more time and expense before you can truly explore quantum.

- Some organizations have started hiring quantum experts as part of in-house teams. These experts are just beginning to create the complex quantum algorithms they believe they will need. The challenge here is the risk associated with the expensive talent, extremely long development timeframes and the ongoing cost of **maintaining quantum algorithms and applications.**

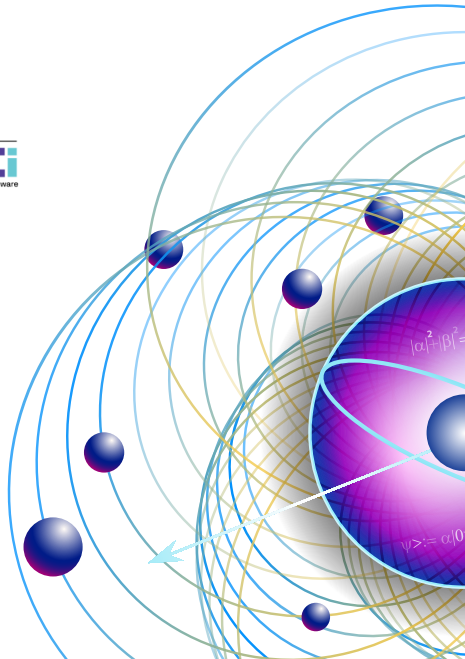
- Others have partnered directly with technology vendors and integrators who are actively involved in quantum computing. This approach serves to eliminate the risk of hiring expensive talent and spending months to years to develop early quantum programs. Many are performing highly tactical testing of early quantum algorithms with small sample sets that can be processed by today's **NISC** quantum computers.

Regardless of your approach, defining a strategic path-to-quantum roadmap is critical to your future success.

How do you begin to explore quantum computing? The figure below shares our path-to-quantum framework for our quantum clients.



As you can see, we define 4 specific phases in the journey to initial quantum production use. For many first quantum uses, a hybrid architecture, where classical and quantum computers help each other, will be the first to deliver quantum optimization and modeling solutions. Some use cases will continue to explore and evolve their applications on pure quantum systems, awaiting a scalable production-ready quantum computer. The QCI path assures your ability to make flexible choices across QPUs and architectures to deliver the optimal quantum impact for your business.



Each phase builds on the exploration and lessons learned from the previous phase, resulting in a logical and strategic approach to learning about and applying quantum computing in your organization.

As quantum computing advances, organizations will loop back to Phase 1 for additional applications and use cases that could not be applied to quantum computing in the previous reviews due to complexity, scale, or other limitations.

Let's examine each phase.

Phase 1: Identify and evaluate to define your best quantum opportunities

Quantum is cool technology. Which means everyone wants to jump in and play with it. That might be fun, but it's not the most profitable focus for organizations.

That's why we recommend that our clients first identify their goals, expectations and priorities for quantum computing. We then work together to define the process for creating, evaluating, and measuring the proof-of-concept projects focusing on their identified quantum opportunities.

The Exploration aspect of Phase 1 is to evaluate current use cases and applications to determine which offer the nearest-term opportunity for quantum value, as well as longer-term opportunities. We review current and future use cases, applications, computations and workflows to understand the data sets, calculations, simulations and operations they perform. We then map their requirements and parameters to the expected abilities of quantum systems to define the best opportunities to begin to explore as quantum-likely targets.

We exit Phase 1 with a well-defined roadmap of current and future use cases and applications to explore as we move to Phase 2 and beyond.

Phase 2: Explore all the quantum options and define your target quantum infrastructure

Quantum computing infrastructures are complicated by the fact that no hardware is alike. A variety of **qubit types**, coupled with diverse programming approaches, means that each and every quantum computer vendor's architecture is unique. Different quantum computers will process different problems, computations, and simulations with different effectiveness, accuracy and performance based on these diverse designs. It is critical that organizations explore all their options to define which quantum computing architecture(s) best meet their processing needs as defined in Phase 1. The availability of quantum computers in the cloud makes a variety of quantum infrastructures available for measurement and testing, today.

The challenge is that to explore and measure processing on a quantum computer, you need to develop a new quantum program. This includes:

- Learning an entirely new software programming paradigm.
- Writing a completely new program in a completely different software programming environment.

- Training today's users to rethink the way they think about their applications and problems so that they can model them in a way that quantum computers can understand and process successfully.

- All of the above requires a significant shift in mindset for current employees concerning your organization and its computations. Or the hiring of expensive quantum experts as a new and unique quantum team.

As we've mentioned before, the SDKs being delivered by today's hardware vendors are:

- **Difficult to use, even for quantum experts**. It can take 8 months to years to write a simple program.

- Require complex low level coding to connect the quantum program with the specific hardware architecture of the vendor. That means that each program is uniquely defined to run on one quantum computer vendor's hardware, locking it to the specific platform.

- To test multiple platforms, you have to code multiple different programs, one for each hardware platform.

- Every time you expand the number of processors (called qubits) or change to the latest and greatest version, you have to **rewrite the low-level code.**

This makes testing and measuring a variety of quantum computers even more complex, requiring larger and larger investments... and risk.

The above software development complexity and resulting risk, including investment and time, is why we created Qatalyst, a ready-to-run constrained optimization software. With Qatalyst you simply submit your problem to one of six function calls. Qatalyst can then solve your problem seamlessly across 4 different quantum computers, as well as running as a quantum-ready application on classical systems. No quantum programming, no coding and re-coding, no hardware lock-in. Simply submit your problem, test and measure seamlessly across popular quantum computers as well as quantum-ready classical solutions.

As part of Phase 2, we work with clients to help them define their intention with regard to quantum software programming; which programs and algorithms they truly want to develop themselves, and which ready-to-run quantum software (like Qatalyst) they prefer to use to decrease their risk and investment while accelerating their time to quantum value.

We test, measure and tune the problems to get the best possible results, across the diverse systems. We identify which vendor's QPU best meets the demands of critical quantum-possible use cases, mapping use cases to the ideal QPU thanks to seamless testing with Qatalyst.

We exit Phase 2 with a preferred quantum infrastructure for both hardware and software, mapped to the opportunities from Phase 1. Our goal is to select an infrastructure that can seamlessly process the priority use cases in the most effective manner possible, preferably without requiring diverse hardware and the resulting complex coding overhead.

We also examine the requirements for integration into the current enterprise infrastructure to begin planning for future requirements.

Phase 3: Quantum testing - quantum potential becomes real

Phase 3 includes testing for pure QPU and hybrid as we explore the power of combining classical and quantum computing to achieve better results in a shorter time frame.

Most quantum experts believe that a hybrid approach will be the solution of choice for optimization as well as other computational applications and use cases. This means that the first uses of quantum will be in a hybrid architecture, which accelerates quantum availability and potentially quantum advantage, ahead of pure quantum applications.

In Phase 3, our goal is to explore, test and measure the value of hybrid and pure QPU architectures for the appropriate applications and use cases we selected in Phase 1. Key aspects include:

- **Developing the hybrid and/or pure QPU software applications needed**, if the decision is to code unique quantum-ready applications. If your organization is developing software, it will be a gating factor on the timing of Phase 3, since the application must be available, tuned, and tested ahead of any further Phase 3 exploration.

- **Deploying/configuring the infrastructure required for the hybrid or pure quantum quantum computing**. This step is simplified by the availability of both quantum and classical computers in the cloud, eliminating the expense and time required to deploy complex hardware. Still, the integration to current infrastructures involving workflows, data access, networks, and more must be planned as part of the roadmap.

- **Running the applications, or solving the problems, using a hybrid and pure environment**. Then tuning, potentially expanding, and running additional problems. This allows organizations to define the optimum problem models, data sets, and approaches within an iterative, expanding process.

- **Measure the results of these runs** for performance, accuracy, and to understand the value of the diversity of answers that quantum delivers as solutions.

  NOTE: We do not expect to see dramatic price/performance advantages at this stage of the path to quantum across all areas of exploration. We do expect to see pointers to the expected value of quantum, and many may see results they have not previously attained due to the diversity of results that quantum processing delivers. We do expect that some computations that are appropriately structured wrt complexity and solution set sizes may indeed approach quantum advantage.

- **Compare these results to current and expected results**. We then extrapolate these results to a larger production-size problem. Since quantum computers will still be facing scalability challenges for the near term, Phase 3 pure quantum exploration will be completed on either smaller QPUs with smaller data sets and problems (created through advanced mathematical analysis) or on quantum simulators that may still require smaller data sets and problems for testing. Hybrid architectures promise to solve larger problems thanks to the blending of classical and quantum processing.

Once the above key aspects are completed, we define a plan for moving forward toward production quantum processing. This includes:

- Specific applications/problems that have proven to provide value from hybrid and/pure pure-quantum environments.
- Prioritization of these use cases/problems for further development, tuning, measurement, and scale.
- Definition of the specific steps and appropriate problem complexity and scale as we advance hybrid and pure quantum processing with more power.
- Expected results including measurements of value.
- Additional software development (if development is chosen) steps for problems, tuning, measurement, and scale.
- Testing different hardware if the hardware selected in Phase 2 did not perform as expected, or new hardware has appeared in the market that shows promise for the specific use cases/applications.

We exit Phase 3 with a wealth of information and measurements on the validity of our planning for the path to quantum. Any adjustments to the plan are made at this point, prior to moving into Phase 4. Phase 3 may continue for a significant time frame for certain use cases that require more scalable resources to solve more complex problems.

Phase 4: First production processing delivers quantum value

Phase 4 is where the proverbial rubber meets the road. We are processing select applications/use cases, most likely using hybrid architectures. These applications are reaching a production level wrt complexity and scale, and we are achieving value from the power of quantum, especially if the software for classical systems is also quantum-ready, which accelerates the overall value of hybrid approaches.

We're also solving small sample problems on pure quantum, continually increasing their scale as quantum machines scale.

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In Phase 4, we're continually measuring the results, tuning problem models to achieve even better results and performance. We're also beginning to look toward more and new opportunities for quantum processing, which means we begin back at Phase 1 and repeat the process with an eye toward scalable, error corrected, pure quantum systems, as well as scalable hybrids, that can and do solve significant problems.

We exit Phase 4 with a continual focus on evaluating advancements that can deliver more effective results than our infrastructures selected in Phase 2. Since quantum hardware is expected to advance and adapt continually, organizations need to constantly be alert to innovations and enhancements that can and will improve their value from quantum hybrids and pure-quantum systems.

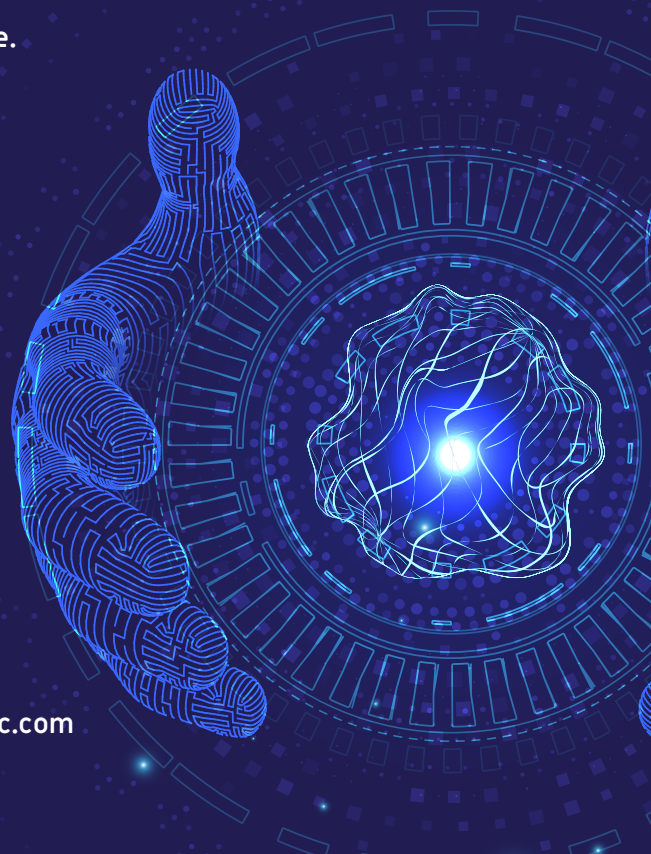
We exit Phase 4 with initial quantum results and a solid plan for moving forward with our first quantum-possible use cases, as they transform to quantum-powered insights. Your team can then return to Phase 1 to begin to investigate the next set of quantum-possible applications and use cases. The journey to quantum continues!

The Bottom Line

Quantum computing technology is already revolutionary. The only questions are when and how it will be best applied to deliver real-world value.

We're helping organizations define their best path to quantum in a vendor-neutral, lowest-risk and investment way. By exploring your quantum-possible applications and use cases in a knowledgeable and complete manner, you'll be at the leading edge of transforming quantum-possible to quantum power.

To learn more about QCI Qonsulting for Path 2 Quantum, **click here.**



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