EXECUTIVE SUMMARY

Preparing for Quantum Computing

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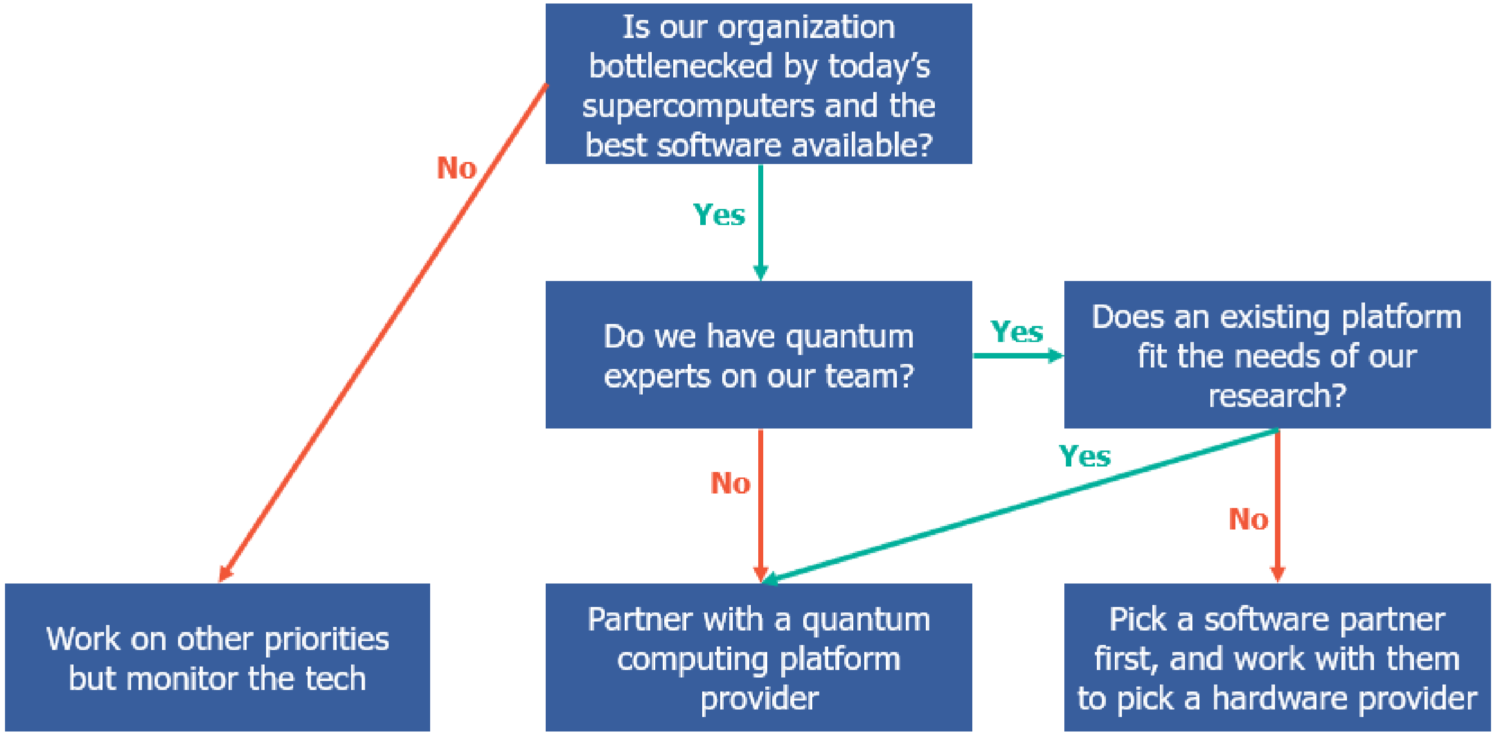
Executive Summary

Quantum computers promise to solve valuable problems that are not addressable by today's supercomputers, such as high-accuracy simulations of quantum chemistry, machine learning, and optimization. However, quantum computers are not yet mature enough to provide advantages for business applications.

Clients who have needs that are bottlenecked by today's supercomputers should engage with quantum computing partners to research business-specific problems. This knowledge will prepare companies to know how and when to use quantum computers as the technology does become mature enough to begin providing value.



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However, there are some problems that even our most advanced computers cannot solve due to their complexity

Chemical Product Design

The time-independent Schrödinger Equation accurately describes molecular systems within quantum chemistry. However, the complexity of the problem grows so much with an increasing molecular system size that the problem is extremely inefficient for even the largest and most powerful supercomputers to solve.

Instead, we resort to techniques that approximate the solution by removing varying degrees of complexity from the problem. Although this makes solutions possible to compute in the real world, there are trade-offs in accuracy.

Supply Chain Optimization

Due to the vast nature of supply chains, there are many variables involved in creating a representative mathematical model. With so many variables, any computational attempt to find the absolute maximum efficiency is generally impractical for a sizable chain.

Today's optimization approaches instead seek to find "good" solutions, though there may not be a guarantee that there is not a better one available. This is a result of searching for optima across a model, and the computational complexity that accompanies the task.

Protein Folding in Pharma

Understanding how proteins fold can help us design better pharmaceutical drugs and target misfolds that cause diseases. Solutions can be found by solving optimization problems that find low-energy states in a space of amino acids.

Unfortunately, the number of possible configurations scales so much with increasing amino acids that the problem can't be completely solved. Optimization and machine learning software is being used to try to approximate answers to the problem, but there is a desire for much more innovation, as evinced by Lux's research on AI for drug discovery.

Other sectors face similar limitations due to the boundaries of today's computation, including energy, finance, logistics, manufacturing, materials, and more.

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Enter quantum computing, a different computing paradigm that promises to overcome the limitations of today’s computers

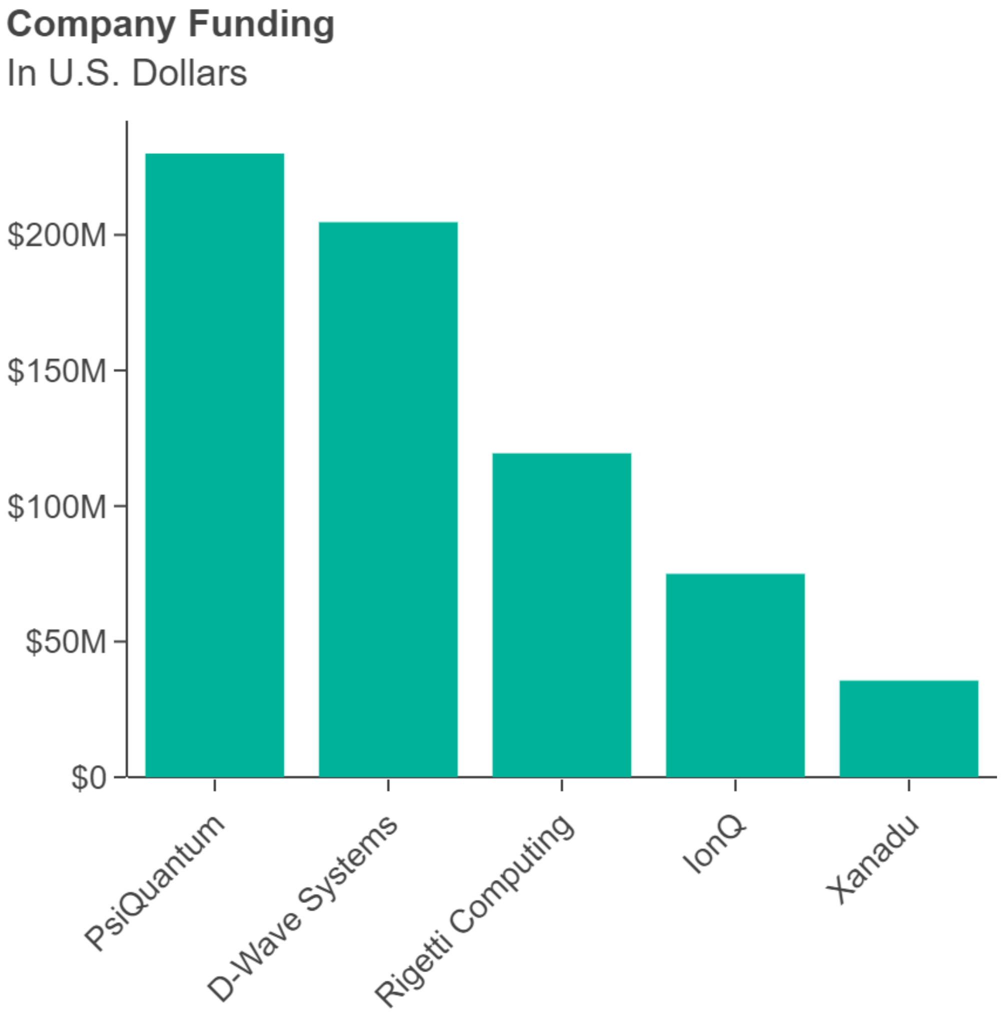
Every computer that we use today – from the supercomputers at national labs to the device you’re reading this report on – is built upon hardware architecture that is governed by the principles of classical physics. We call this **classical computing**.

Quantum computing, born from research in quantum physics and computer science in the late 1900s, works in an entirely different manner from classical computing. For the purposes of this report, we won’t delve too deep into how* quantum computers work (though we will address basics later on). Instead, we will primarily focus on what they do and why that is important. The first major point to understand is that the architecture of quantum computing is fundamentally different from all other computing, which is part of what makes it useful.

Classical Computing		Quantum Computing
Uses classical physics Smartphones Supercomputers Autonomous Vehicles Quantum computer simulators	≠	**Uses quantum physics**

*For more in-depth descriptions of quantum computing, see here for an introduction to the physics, and here for a computer science perspective.

With accelerating innovation, companies are investing heavily in quantum computing both internally and externally



The majority of external funding comes from a few very large investments. **The top five highest-funded startups in the space (left) have raised about $630 million to make up roughly 60% of external funding.** Notably, they are all hardware companies, which tend to be capital-intensive.

In terms of internal funding, it is likely that billions have been spent on development. In 2018, IBM claimed to have spent **$38 billion** on research and development for emerging digital technologies like quantum computing and AI since 2013. Other competing companies like Microsoft, Google, and Fujitsu are likely spending similar amounts to assemble their own platforms.

Early case studies indicate that developers are broadly targeting three major problems using quantum computing

The three major problems targeted by quantum computing are:

1) The Simulation of Quantum Systems

2) Machine Learning

3) Optimization

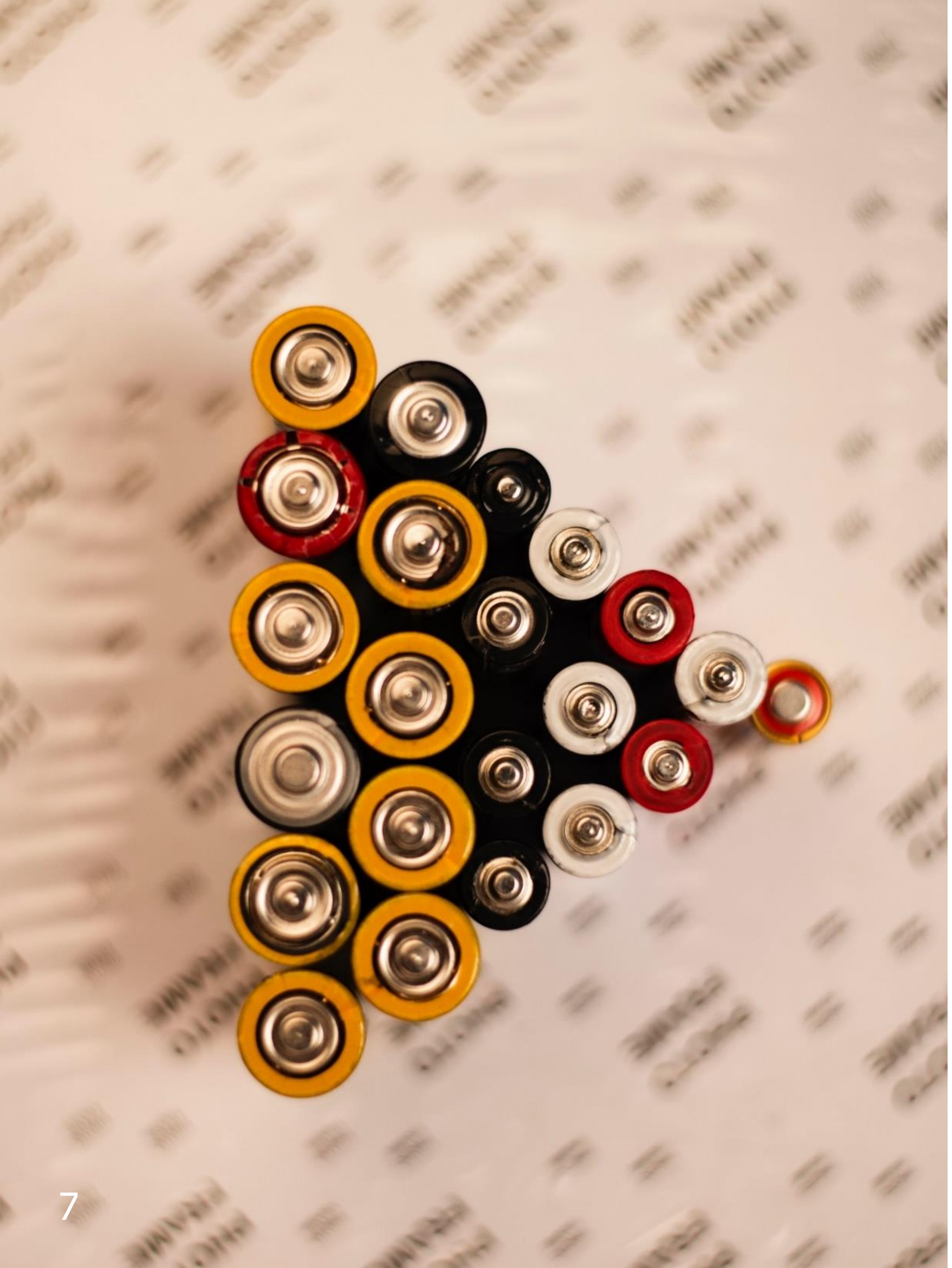
Why do developers target these areas?

Quantum algorithms have all been designed for these classes of problems that take advantage of quantum computers in ways that outclass classical computers. This is typically due to the exponential growth of problem sizes in these areas.

Furthermore, none of these problems require exact answers. As long as quantum computing can provide a better solution – either more accurate or faster – than classical methods can, then quantum computing will become a useful approach. This approach of “not perfect, but better” is extremely important due to the limitations of the early-stage quantum computing hardware available today.

USE CASES – SIMULATION OF QUANTUM SYSTEMS

Mitsubishi Chemical looks toward advances in Li-air batteries



One of the great promises of quantum computing is that it can enable superior simulations of chemicals and chemical reactions, which are, after all, themselves quantum mechanical systems. Mitsubishi Chemical is working with IBM to explore such applications in batteries. Much of the work in quantum computing has focused on relatively simple molecules as demonstrations, so moving toward addressing practical challenges like Li-air anodes is a notable step, even if the work is still in early stages.

OTHER EXAMPLES

- Developers often cite the target of creating a more energy-efficient fertilizer by analyzing nitrogenase
- OTI Lumionics uses quantum computing for OLED display design

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There are significant challenges to development that limit quantum computing in the near term

Quantum computing has experienced a sharp rise in interest due to some early technical achievements, which has led to patents, investments, and hyped news headlines, as we highlighted earlier.

While pilot research projects are occurring in small pockets, there is certainly no widespread adoption of quantum computing. **Today, there are no examples of a quantum computer providing value for users that could not be achieved with a classical computer.**

Major challenges still remain for hardware development, and **it is the bottleneck for further technology development**. With limited hardware, software developers are forced to work within the confines of limited machines.

Companies with high quantum expertise can piece together partnerships from both software and hardware players

1 SOFTWARE

Computer programs for quantum architectures

2 HARDWARE - PROCESSOR

Developers of quantum computing processing hardware

Outlook

1 **As useful quantum advantages are developed, they will be attached to outside software platforms**
As quantum advantages emerge for business use cases, they will be added to existing enterprise software platforms rather than sitting solely within quantum computing organizations. Watch for partnerships between quantum players and other software players like chemical informatics.

2 **The developer landscape will largely grow out of academia**
Due to the novelty of the technology and expertise required to develop it, most innovators will emerge from academia rather than existing industry talent. They will either spin out of research labs or feed into existing players.

3 **Expect continued funding in the space**
Though quantum computing is primarily a research project right now, it will have continued financial support. This is due to its potential to solve novel high-value problems, which cloud giants in particular (Amazon, Microsoft, etc.) want to own within their platforms.

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