Quantum Computing: Applications, Software And End-User Markets

January 2018

2025 Library Ave., Suite 402
Crozet, VA 22932
www.cir-inc.com sales@cir-inc.com
Tel: 434-872-9008 Fax: 434-872-9014

Quantum Computing: Applications, Software and End-User Markets

Report Description

This report examines the major applications for quantum computers. Questions answered in this report:

- Which end-user communities will be the first to adopt quantum computing and what is the timeframe in which they will need to migrate from classical supercomputers to quantum computing platforms?
- What software will be required for early-stage quantum computing and how is that likely to evolve over the coming decade? What can quantum computing software do today and what will it be able to do in the future?
- Will quantum computing be delivered via a cloud or from on-premises corporate computers?

This report will also provide a ten-year forecast of revenues generated by all of the key quantum computing applications with breakouts by hardware, software, services, geography and end user types for each application. In making these forecasts, we are particularly concerned with determining when the major inflection points in the sector will occur and why.

The report will also include profiles of leading quantum software and cloud services firms. Some of the applications considered in this report will include quantum chemistry, advanced search engines, simulation, routing/scheduling, logistics and analytics, cybersecurity and machine learning/AI. The impact of such issues as user friendliness for programming, and the response to quantum computers from the classical computer community will also be discussed.

Table of Contents

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

List of Exhibits

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

Chapter One: Introduction

1.1 Background to this Report

1.1.1 An Inflection Point Arrives for Quantum Computing: More to Come

A quantum leap in computing: Quantum computers bring a major inherent advantage to solving supercomputer-class problems in a potentially very broad range of applications. For classical computers of all kinds—including supercomputers—bits are either 1 or 0 and are represented by electrical states in classical circuits. For quantum computers qubits are defined as the equivalent of bits and are represented by quantum states in specialized material systems. However, while an ordinary bit can be either a 1 or a 0, a qubit can be both a 1 and 0 at the same time.

That means two qubits can represent four numbers at the same time, three qubits can represent eight numbers, and nine qubits, 512 numbers simultaneously. In other words, their capability increases exponentially. Therefore, in quantum systems the number of numbers (N) that can be processed increases according to the formula “2 to the power N” while in classical computers it increases according to the formula 2N.

This statement provides in a nutshell why quantum computers are so much more powerful than classical computers but also ignores the numerous problems that are in the process of being solved in order to build actual working quantum computers. Such problems range from quantum computer design and materials, through how to interpret the output of quantum computers, through how to generate sufficient robust qubits to solve real-world problems.

From the perspective of business analysis, the opportunity presented by quantum computing consists in measuring the cost of solving the outstanding physics and computer science issues surrounding quantum computers and assessing them against the value of solving problems that are apparently intractable to classical supercomputers in any reasonable period of time. This effort was until very recently basically a “science project,” since there were no commercially available quantum computers that could be used to solve practical problems. This is changing in important ways.

Commercial quantum computers are here: IBM and D-Wave now both have quantum computers on the market that apparently can be used for practical applications. At the time of this writing, Intel (in conjunction with Delft University) and Rigetti are about to launch their machines in the next few years.

Waiting in the wings are 10 to 20 other firms that plan to introduce quantum computers soon. These include not only some start-ups but giant computer/communications industry firms, notably Microsoft and Nokia Bell Labs. Google has been working on cloud-based quantum computing offerings. Meanwhile, smaller firms are betting significant amounts of money on the future of quantum software.

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

The arrival of commercial quantum computers is opening up many new opportunities that extend well beyond hardware. We are already seeing specialized quantum software firms emerge and there are also software firms for which quantum computing may prove a technology to be leveraged. For example, there are perhaps hundreds of machine learning start-ups and it would be no surprise to see some of them adopt quantum computing as part of their technology mix over the next few years.

A more immediate opportunity—the most immediate, actually—is to supply software and services for software and end-user firms that at this early stage are merely simulating quantum computers in order to learn more about what they can offer in the future. This type of simulation consists of classical computers able to simulate quantum bits and quantum gates, with varying degrees of accuracy. The largest simulators can already simulate quantum computers with the number of qubits in the high 40s—the point that commercial quantum computers have actually reached. The best simulators can simulate accurate levels of noise. There are also software companies working on quantum algorithms that could be used on any platform and are currently designed using simulators.

Performance improvements in quantum computers are accelerating: Quantum computing has also seen considerable performance improvements in the past couple of years. The number of qubits that can be handled by quantum computers and (more controversially) the quality of those qubits is increasing. In addition, there are more effective algorithms and more user-friendly programs for quantum computers.

Potential commercial end users for quantum computers are emerging rapidly: As CIR sees it, we are shifting into a new era, where planners and designers will move into the quantum computer end-user base, supplementing the engineers and programmers who have been the main users of quantum computers for the past decade.

As part of this evolution, end-user organizations increasingly include large commercial firms and not just the government, military and national science institutes that have been the organizations that have “kept hope alive” in the quantum computing sector for the past decade or more. As an illustration of what we mean here, firms that are now experimenting with quantum computer applications include Biogen, DowDuPont, Goldman Sachs, Lockheed, Siemens, Volkswagen, etc.

Much more attention for quantum computing in the general media: At the same time quantum computing is receiving a considerable amount of attention in the business press; *The Economist* being notable in this regard. Quantum computing now has a business-oriented conference all of its own—Q2B. Until 2017, quantum computing literature and conferences were almost exclusively of the technical kind.

As CIR sees it, the above trends considered together constitute an inflection point for quantum computing applications, with the strong likelihood that significant revenue generation will soon occur. The fact that powerful firms such as Google, Microsoft and

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

Nokia are getting into the quantum computing business, that venture capital is being directed to this sector, and that large end users see quantum computing as having applications outside of R&D are all indications that something has changed.

1.1.2 Many Applications Issues still to be Resolved

However, breathless accounts about quantum computing and the huge potential of quantum computing in the general business press notwithstanding, the fact remains that no quantum computer can yet beat a supercomputer in terms of actual performance. We may well be very close to the era of "quantum superiority," but we are not yet there. At the time of this writing both Google and IBM seem on the verge of announcing the arrival of quantum superiority, but not in a general-purpose quantum computer, but rather in something more specialized.

CIR notes that even when we enter an era where "quantum superiority" is beyond doubt and is demonstrable in general purpose quantum computers, there may still be many problems that will be beyond the capabilities of practical quantum computers. Put another way, for years to come it will be provably the case that a sufficiently powerful quantum computer could solve certain problems in a reasonable period of time, while a classical supercomputer cannot do so. Yet at the same time, that "sufficiently powerful" quantum computer may still be years from being built.

Perhaps at some point off-the-shelf quantum computers will become sufficiently powerful and sufficiently ubiquitous to be effectively unlimited in their applications. But nothing like this scenario is worth considering from the perspective of generating revenues—or estimating those revenues—in the quantum computing market today. First, a number of applications-related issues must be resolved. These are profiled in Exhibit 1-1

Exhibit 1-1: Applications-related Issues Outstanding in Quantum Computing

Issue	Nature of Issue	Timing for resolution
Quantum superiority	We still don't know for sure if there are practical problems in industry and government that cannot be solved using classical supercomputers running the best protocols and algorithms	Theoretically, there are such problems. There are already several large organizations trialing quantum computers or emulation of quantum computers in belief that they will encounter real planning and design problems in the next few years that will be unsolvable using classical computers. We are near to, but not at a point where commercial quantum computers are provably superior to classical computers. There are differences of opinion about when this might occur. Generally, the consensus is two to five years.

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

Exhibit 1-1: Applications-related Issues Outstanding in Quantum Computing		
Issue	**Nature of Issue**	**Timing for resolution**
Access to quantum computer resources	As with all computer resources, quantum computers can be accessed over a network/cloud or deployed as a premise computer in the enterprise	The consensus is that initially quantum computers will be accessed on a cloud. IBM has provided researchers access to a quantum computer for a number of years and Google is building a business around quantum computing on a cloud. However, given the history of the computer industry, it is hard to believe that enterprise-grade quantum computers won't emerge as a significant market in five plus years.
First revenues	Which end users and applications for quantum computers will become the first significant generator of revenues for quantum computing	Other than government and military users, the answer to this question is still unclear. In the literature there is some indication that first revenues will come from specialty chemicals, pharma and financial services firms, and that when the quantum superiority barrier has been crossed, the impact will be immediate
Human factors	Quantum computing is only just emerging from being something close to the proverbial "science project." User friendliness and technology experience is currently a drag on quantum computing	Human factors must be resolved at a number of levels. Notably for quantum computing to take off commercially the industry will need programmers and application developers that are sufficiently familiar with quantum technology to develop commercial software. There is a distinct shortage of such personnel at the present time. This is partly a matter of training. But in addition, quantum computer firms must bear in mind that the more they can make their machines like other large computers (using standard programing languages, for example) the more machines they will sell.

Source: CIR

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

1.1.3 The Emerging Business Case for Quantum Computing Applications

Two sides to quantum computing hype: Another issue in addition to the issues listed in Exhibit 1-1 is the "hype factor," which is present in all rising technology markets. In fact, quantum computing hype is already on the rise. By way of example, a recent article in Forbes claims that "in the same way that steam engines and microprocessors once redefined entire industries, quantum computing could herald the advent of as yet unimagined businesses and sectors, while also opening new avenues for current sectors, such as chemical and pharmaceutical development, oil and gas exploration, financial management, and even nuclear fusion and artificial intelligence."

This kind of "analysis" can confuse investment, making it seem as if there is a lot more to the quantum computing market in terms of money making than there really is. CIR has seen such hype in other technology-oriented markets before—most notably in the optical networking market at the turn of the century, when ill-considered hype about bandwidth demands of the Internet led to a massive boom followed by a massive crash.

CIR wouldn't be that surprised to see something like this happen in the quantum computing market. But we should also note that hype has a useful side. It may serve as useful "propaganda" for quantum computing in that it stimulates the interest of investors and keep entrepreneurial spirits high.

Quantum computing applications are real and diverse: From our perspective, the strongest business case for quantum computing is that its applications are both real and diverse. However, much money quantum computing ultimately makes for the firms and individuals investing in it, CIR is sure that quantum computing is a lot more than just a "cool" technology crying out for someone to discover a viable application.

Our sense of the market is that the specialty chemical and "big pharma" sectors, in particular, will very quickly buy into quantum computing, because potentially quantum computing can decrease the time to discover new materials and drugs and therefore contribute directly to the bottom lines of the firms in these sectors. We think that this is especially important these days, since many of the "great discoveries" have been made and it is harder than it once was in the pharma and materials science industries to dream up new products.

We think that a strong business case can also be made for quantum computing applications in big financial services firms. Here, quantum computer-based optimization and simulation have the potential to save firms millions of dollars. For other commercial applications of quantum computers, business cases may not be as robust but they are certainly there to be discovered and implemented. Quantum-computing based machine learning and AI will benefit from the high level of interest in those topics independent of the role of quantum computing, quantum computing-based cybersecurity markets will be boosted by the threat that quantum computers create for public key encryption systems,

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

and so on. In fact, much of this report will be dedicated to the process of analyzing the markets for quantum computing in these areas and more

Before any of these applications take off in a big way, quantum computers from reputable companies will have to handle at least 50 high-quality qubits, which is to say, 50 qubits with relatively little noise. There is also a need for quantum computers to provide a high level of interconnection. As we have already noted, we are probably just a couple of years from all these performance requirements becoming a practical possibility and when this happens, the next big inflection point in quantum computing will have arrived—an inflection point marked by true quantum superiority.

1.1.4 The Next Three Inflection Points for Quantum Computing

A central theme of this report is that the quantum superiority inflection point will gradually expand the market from the pioneer firms that are already exploring how quantum computers may help their organizations in the future (i.e., without any immediate prospects of positive cash flow) to those that can make immediate use of quantum computing with an immediate (or least quick) impact on the bottom line.

When this occurs in the next three to five years, the number of potential quantum computer users will most likely expand by an order of magnitude. At the same time, we anticipate penetration of this addressable market to increase sharply. CIR anticipates that new applications and a variety of large firms will start to be added to the list of end-user communities that make effective use of quantum computing.

CIR expects this general growth pattern in quantum computing to dominate the quantum computing business, until the next inflection points kick in. We expect there to be a total of four inflection points during the ten-year forecasting period covered in this report. We note, however, that the exact timing of these inflection points will be very uncertain.

Unique quantum-enabled products—second inflection point of quantum computing: The next of these future inflection points will occur when some company introduces a new and useful product or service that could not have been brought to market without quantum computing and which receives a great deal of publicity in the tech community.

When this happens, we would anticipate that the revenue from quantum computing will once again take a great leap forward. What will have been proved at this second inflection point for quantum computing is that not only can working quantum computers be built, but they can solve problems/design products and services that some end-user community cares deeply about. It will still then be possible for someone to come up with an algorithm that can solve the same problem using classical methods, but at some point that development might come too late—quantum computing will have made itself the go-to technology in a particular niche and will be difficult to displace.

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

General purpose quantum computers—third inflection point of quantum computing: As we discuss in more detail in the main body of this report, there is an ongoing discussion in the quantum computing world about special purpose vs. general purpose quantum computers. No one doubts that the eventual goal of quantum computer engineering is to produce a general-purpose computer in the same sense that a classical supercomputer is a general-purpose computer.

However, for now commercial quantum computers are not really general-purpose machines in the sense that is usually understood in the computer industry. Most obviously, the D-Wave machines have been designed specifically to solve optimization problems. At some point, however, quantum computers will be able to make the claim that they are general-purpose machines in the way that a Cray, or for that matter a PC, is a general-purpose computer.

Some would argue that if a quantum computer isn't a general-purpose computer, it isn't really a computer at all. More than just a philosophical point is being made here. Until quantum computer manufacturers start to offer machines that can compete with classical computers across the full range of problems, their market will be restricted to special-purpose adjunct processors. Based on this, CIR anticipates that the arrival of general-purpose quantum machines will bring quantum computers to a broader range of applications and create the need for new kinds of software. But we don't think that this third inflection point in quantum computing market evolution will occur for at least another five years.

Following this and towards the end of the ten-year forecasting period considered in this report, we anticipate yet another inflection point in which the cost of quantum computers has dropped to a point where a significant number of large organizations can afford to install quantum computers on their premises, perhaps in a large data center. Such organizations may then distribute the computing power among users in their organization through some kind of private cloud.

Enterprise-class quantum computers—fourth inflection point for quantum computing: At the present time, there is probably a consensus in the quantum computing community that low-end quantum computers are not likely to appear for decades, if ever. Given the high price of quantum computers and the early stage of quantum computing at the present time, this is a plausible belief.

The problem is that this belief seems to run counter to the history of computing, which seems to prove that whenever there is an innovation in computing this moves down market as a result of miniaturization. Thus, the minicomputer of the 1970s, which was widely installed in large corporations, was replaced by the personal computer by the 1980s which became installed in organizations of every size.

Could something like this happen with quantum computers? As we have already noted, the weight of opinion in the quantum computing business is that it will not. Nonetheless,

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

CIR believes that towards the end of the forecast period, smaller quantum computers will have appeared that will be reliable and low-cost enough to be deployed on the premises of a variety of smaller educational, financial and R&D organizations.

Thus, in this fourth inflection point the addressable market for quantum computing will expand once more creating greater revenues and the need for new kinds of software. This development would also take quantum computing applications out of being entirely a realm dominated by cloud delivery. To be clear, CIR believes that quantum computing PCs will remain a fantasy, since it is very hard to imagine what a user could do with a quantum PC.

However, we think that a quantum computing market in which the market has expanded to sales of several thousand machines per year is a distinct possibility. We incorporate this into the forecasts presented in this report, but this inflection point will not occur until the last couple of years of the forecasting period discussed here.

1.2 Objective and Scope of this Report

1.2.1 Primary Goals of Report

The primary objective of this report is to quantify the commercial opportunities that are emerging from applications of quantum computing over the next decade. Our strategy to achieve this objective is (1) to establish when inflection points are likely to occur in the quantum computing market, what these inflection points will look like, and what qualitative impact they will have on revenue generation from quantum applications and (2) to estimate just what the level of revenues will be from quantum computing applications, software and services over the coming decade.

Some of the applications considered in this report include quantum chemistry, advanced search engines, simulation, routing/scheduling, logistics and analytics, cybersecurity and machine learning/AI. We have also paid special attention to the quantum computing applications used in the transportation, financial services, chemical and pharmaceutical industries, which seem to be the markets where quantum computing will find first use. Although we do discuss government and R&D applications for quantum computers, the focus of this report is on the use of quantum computers in enterprise computing over the next decade.

The impact of such issues as user friendliness for programming, and the response to quantum computers from the classical computer community will also be discussed.

Ten-year forecasts: With regard to (2) above, we include in the Executive Summary of this report a detailed ten-year forecast of quantum computing applications. These are broken out by end-user sector and we provide commentary on the type of functionality (for example, optimization or simulation) being used by each end-user sector. Where possible we have provided volume forecasts (of computers) as well as value forecasts, but given the early stage of quantum computing this is not always possible. In addition,

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

to breaking out our forecasts by the type of application, forecast breakouts have also been provided of software and access technology (cloud or premises computer).

However, because this report is primarily about applications, we do not include much granularity on forecasting the market for quantum computers themselves; such a forecast will be provided in detail in a later CIR report. However, the software forecast provided in this report obviously depends to some extent on the number of quantum computers deployed and we provide a forecast of quantum computing shipments that is sufficient for this purpose. In making these forecasts, we are particularly concerned with determining when the major inflection points in the sector occur, why they occur, and what revenue impacts they are likely to have.

Later in 2018, CIR will be publishing a report that specifically predicts quantum computer sales, with the appropriate breakouts.

1.2.2 Company Profiles Provided

In addition to the goals set out above, this report also assesses the strategies of some of the key firms that anticipate generating significant revenues from quantum computing application in the next decade. We achieve this goal through profiling three types of leading firms in this space.

Quantum computer firms: We examine the software and applications orientation of the leading quantum computer firms themselves (e.g. D-Wave), since all of these firms have declared views on how they will handle software and programming issues and what applications they are pursuing. Our focus here is on the handful of firms that are already selling or will soon sell quantum computers and that already have stable strategies as far as software and applications targeted.

Software firms: Second, we examine the strategies and objectives of the smaller software firms that are now burgeoning in the quantum computing space. As with our profiles of the software/applications targeted by quantum computer firms, this is not a complete listing presented here, but rather a review of what some of the more established firms developing software for quantum computers are doing, and why.

This is an area where we anticipate there will be a rapid expansion in the number of firms over the next five years or so, because the barriers to entry in this market segment are relatively low and entrepreneurs with a good knowledge of both quantum physics and IT will most likely be able to cash in. Part of the reason for profiling software firms is to determine what software will be required for early-stage quantum computing and how this is likely to evolve over the coming decade. This part of the analysis answers the question: what can quantum computing software do today and what will it be able to do in the future?

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

End users: Finally, we take a look at the pioneer end users of quantum computers, which is taken to include end user firms that are trying to better understand how quantum computing can help them in the future through quantum computing emulations on classical computers, rather than using quantum computers themselves. These include a handful of "tier 1" banks, aerospace firms, automotive firms, etc. that are openly working with quantum computing—or at least quantum computing emulations—with an eye to future enterprise applications.

In addition to profiling particular firms, we also determine which end-user communities will be the first to adopt quantum computing and in what timeframe they will need to migrate from classical supercomputers to quantum computing platforms.

1.3 Methodology of this Report

This report has used the eclectic research methodology common to all CIR reports for almost thirty years that our company has published reports in the data communications and enterprise computing sector. We have collected information from a variety of both primary and secondary resources.

1.3.1 Primary Research

As far as the primary sources are concerned, these have consisted of personal and telephone interviews with key executives of firms actively pursuing the quantum computing business opportunity.

Q2B conference: Some of these interviews were conducted at the Q2B 17 conference, which was the first conference ever to focus on the commercial future of quantum computing and of quantum *enterprise* computing especially. The author of this report was a speaker at this conference and was therefore able to discuss in-depth and face-to-face where and when commercialization of quantum computing is likely to occur.

1.3.2 Secondary Research

Much of the raw information that we analyze in this report is based on published sources of several different kinds. We have examined the technical literature in this field with the goal of better understanding in a hype-free fashion, how close quantum computing really is to its goals.

We have also examined the "quality" business press and important computer trade magazines in order to keep up to date with the latest developments in commercial quantum computing. From the perspective of this report, the important developments include new software and programming developments at leading quantum computing companies, business announcements from quantum computing software companies, announcements of major new applications and pioneer users of quantum computing, alliances and quantum software-related investments.

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

1.3.3 Forecasting Methodology

The forecasting methodology used in this report is discussed in more detail in the main body of the report. However, we provide an overview of the approach adopted here. Essentially, the forecast methodology begins with a quantitative assessment of the number of potential users of quantum computers and ends with revenue forecasts with breakouts by software, services, applications type and end-user community. We also take a view of where—geographically speaking—the revenues will come from.

Quantum computing is, by common consent, at a very early stage of commercial development and many people in the industry itself are still somewhat agnostic about its likely evolution. However, in order to develop the forecasts that are central to the objectives of this report, we have had to take a view on the likely penetration of the available market by the products and services discussed here and of quantum computing more generally. In this regard, we have been primarily influenced by the four inflection points that are discussed in this chapter and throughout the report. We have also taken what we believe is the non-controversial view that current revenue generation from the markets that we are most interested in in this report are quite small.

Forecasts of functionality and end-user categories: In order to break out our estimates of quantum computing applications/software revenues by applications and functionality types, we have taken into consideration how quantum computing is being used today and adopted market shares by application accordingly. For example, a lot of what is done in the quantum computing space these days can be categorized as optimization. This may just reflect the current preeminence of D-Wave systems, but nevertheless, remains the case and this is reflected in the forecasts presented here.

The literature offers no consistency about what functional categories are appropriate to use for breakouts of quantum computing applications and with this in mind, we have tried to suggest some in Chapter Three. We hope that these categories will be useful to readers of this report, but also that others will be able to build on what we have provided to make it more useful.

Similarly, a few end-user communities appear to be prominent at the customer end of the supply chain for quantum computing. Notable among these are R&D, military and government, material design, financial services and commercial aerospace. Our forecasts reflect these patterns, although we note again that a primary goal of this report is to project the future of quantum computing in enterprise computing, a market whose potential is so much larger than military and R&D applications—at least in the long run.

At the present time, the consensus view is that quantum computing will be delivered primarily over cloud services and—as discussed earlier in this chapter—there are good reasons for thinking this scenario to be plausible. Obviously, such a restrictive scenario has a negative impact on the market potential for selling quantum software, since fewer quantum machines will be deployed. However, there is also some potential for selling

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com

quantum computing-related software at the client end. In addition, as already noted, we allow for the possibility of smaller quantum computers being installed at the end of the forecasting period considered here.

Finally, we include a geographical break out. Currently most of the pioneer users of quantum computing are located in the U.S. But we anticipate that this will begin to change quite quickly as government funding for the commercialization of quantum information technology in Europe and Asia begins to change quite quickly.

What we are presenting here is a "point forecast," which we believe represents the most likely scenario for the market evolution of quantum computing. However, we acknowledge that there are other possibilities and these are explored throughout the report.

1.4 Plan of this Report

This report consists of four chapters and an Executive Summary. As with other CIR reports, the Executive Summary is designed to list what CIR's experience suggests are the main opportunities likely to emerge from quantum computing applications and software markets in the next ten years.

In Chapter Two we have reviewed and analyzed the technologies and strategies being deployed by commercial firms focused on the quantum computing business opportunities. We begin by taking a look at the handful of firms that have quantum computers ready—or almost ready—for commercial deployment, focusing especially on their strategic thinking about applications and software. We also examine the new breed of quantum software firms and products and how they plan to make money in these early days of the "quantum computing revolution"

In Chapter Three, we take a first look at the demand side of the quantum computing market. The goal of this chapter is two-fold. First, we illustrate how real end users, especially those in large corporations are making the first tentative steps to actually using quantum computers. Second, we propose an analytical framework and carry out an actual analysis in order to show how the demand for quantum computing applications and software is likely to evolve in key end-user communities.

Finally, in Chapter Four of this report we have developed detailed forecasts of revenues from quantum computing software, services and other applications-related sources based on CIR's view of market evolution patterns and where the major inflection points are likely to occur.

2025 Library Ave., Suite 402,
Crozet, VA 22932
Tel: 434-872-9008 Fax: 434-872-9014
www.cir-inc.com sales@cir-inc.com