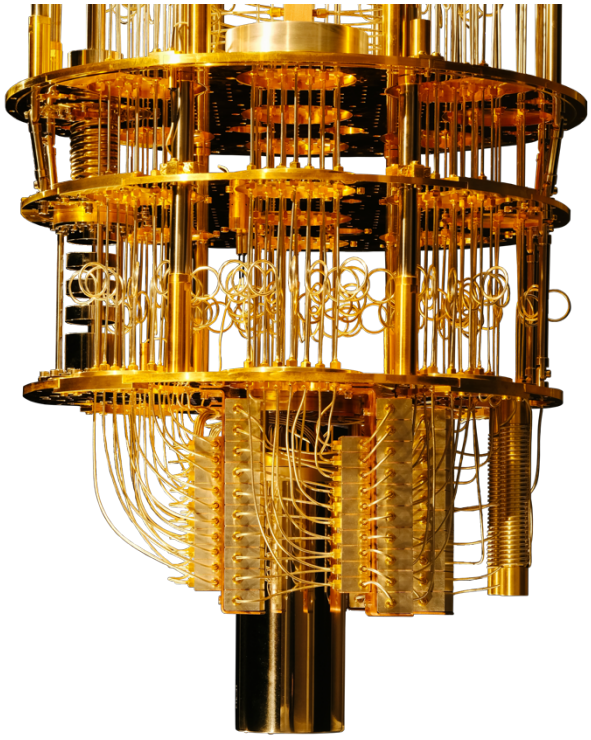
# The new Turing machine, but the world is chasing after it like a space race.

**By Riccardo Murciano**

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## 1. Introduction

Quantum computing represents the new frontier of computational evolution. Experts claim that in less than 15 years quantum computers will be able to process at a speed that would surpass by far the compound computation power of all currently existent hardware (IBM, 2020). Things that we would once have said unimaginable are becoming part of our reality. Achieving quantum supremacy is one of the monumental discoveries that will revolutionize history. Unsurprisingly, the world's biggest economic forces and multinational enterprises are extensively investing in this technology, similar to how humankind acted around five decades ago with the space race. In the US, the National Science Foundation and the Department of Energy initiated a $1 billion investment plan for the coming 5 years (Department Of Energy, 2020). In China, the government invested $10 billion in quantum research facilities in Hefei (IDQuantique, 2018) since 2014 and recently Google claimed to plan a “several billion” spending for a fully-capable quantum computer by 2029. (Castellanos, 2021)

Although, this technology brings uncertainties along with it, one important being the compromising of today's cybersecurity. This is why the debate on their implications for network security and the threat that quantum computers will sooner or later break the security protocols with which our data are transmitted and stored are under particular spotlight. Consequently, it is difficult to evaluate the threat-benefit ratio for this specific invention. This essay will therefore further investigate four topics that are worth mentioning. First, it will give a short introduction on the point we reached in the quantum computing advancements. Secondly, it will examine why it represents a shift to current cybersecurity protocols. Thirdly, it will analyze the impact it could have on industries with a closer look at the sustainability aspect. Fourthly, it will investigate the most fitting business model for quantum technology and deliver an explanation on what aspects can give valuable insights on future leading

potentials in the sector. Lastly, this paper will conclude with practical recommendations on an entrepreneurial level.

## 2. What is a quantum computer?

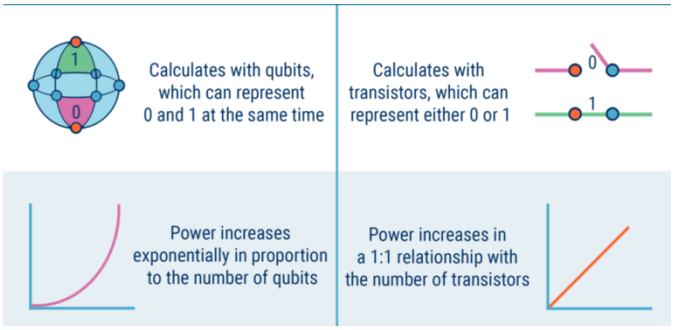



*Figure 1 - Difference in operating technology of quantum computers (on the left) and "classical" computers (on the right)*

As mentioned earlier, the field of quantum mechanics and its application in the world of information technology has gained an important spotlight in recent years, but what makes this technology so worth keeping an eye on?

Quantum computing does not share many (if not any) aspects with the physics behind computers as we know them today. Hence, a quantum computer operates following a non-classical computation model: while traditional models such as the Turing machine are based on "classical" representations of computational memory, a quantum computation can transform memory into an overlap of several states of a classical type (Sher, 2021). To be more clear, digital information in a “classical” computer is represented by bits, which can be set to either 1 or 0. Four bits can be in 2^4 different configurations, which are 16 configurations from which only one can be used at a time. Conversely, a quantum computer uses qubits, which are in a special subatomic state called “superposition” which enables them to be in all of those 16 configurations at once. More interestingly, with each extra qubit, the number of configurations grows exponentially, meaning that for instance 18 of them can already store a value of 262.144 (2^18) configurations. 64 regular bits can equally represent this huge number (2^64=18,446,744,073,709,600,000 combinations). Such information-load would take an average computer approximately 400 years. This means that quantum computers could process problems that are essentially impossible for “classical” computers (O’Neill, 2021)

## 3. Will there be new standards?

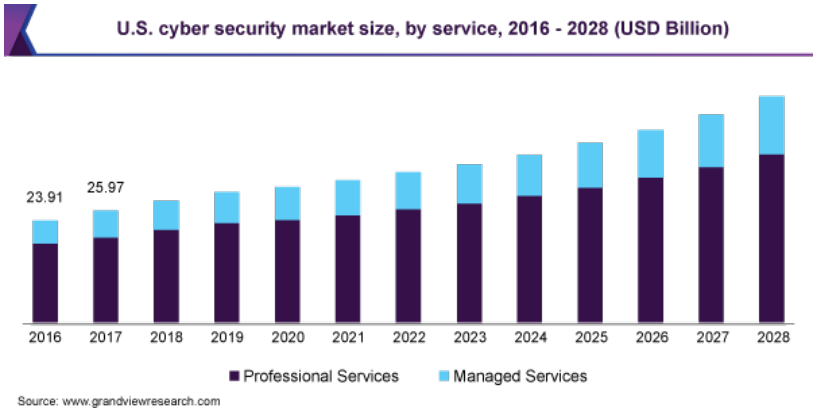
*"The fate of human civilization will depend on whether the rockets of the future carry the astronomer's telescope or a hydrogen bomb." - Sir Bernard Lovell, 1958*

With Einstein's extraordinary discovery of the worldwide known relativity theory E=mc^2, humans were able to answer endless scientific questions. But all that glitters is not gold, such formula was also reason for discovery of the mass-destructive atomic bomb, which caused more than 200.000 deaths (Lifton, 1991). Similarities can be found when arguing about the opportunities and threats of quantum computers. In research from National Academies of Sciences, Engineering, and Medicine et al. (2019), it is mentioned that quantum computers will be more suitable for optimization problems that mathematically aim for **one solution**. This means that, according to recent research, finding a password and therefore decrypting a secure file will be a child's play for quantum computers in the near future. This could represent an important threat for today's cybersecurity systems that prevents our personal data from being sabotaged and hacked. On the other hand, groups of scientists have claimed that there can be solutions to future quantum attacks like new generations of cryptography, which rely on mathematical problems based on conventional ciphers rather than on traditional discrete and factoring logarithms (Mosca, 2018). There are uncertainties on these topics, how will quantum technology impact today's security systems?

*Hypothesis 1: Quantum computing will set a new standard of cybersecurity.*

It is not clear how this new field of technology will affect the world of encryption as we know it today. Nevertheless, many researchers and scientists predict that the future is clearer than it looks. The fact that the market size of cyber security is gaining increasing interest in large

continents such as the US *(See Graph 1)*, can be an indicator of the chances of preparing for a more security-threatening future. Additionally, as depicted in the data in Graph 1.0, the estimations for the coming 7 years state that cybersecurity will gain importance at an even higher level compared to before. (Grand View Research, 2021)




*Graph 1 - Size of cyber security market in the US, 2016 - 2028*

In a future scenario in which a quantum computer algorithm will be able to easily unravel all modern internet-cryptography, Head of Cybersecurity at Cambridge Quantum, Duncan Jones, believes that the only way to counter such menace is to use the same quantum technology to develop the security system. Security-leading technologies such as blockchain can be a way to create quantum-proof security. Further development in those industries, with the implementation of quantum computing, will most likely make it harder for a future robust quantum computer to hack security systems (Jones, 2021). In conclusion, the aforementioned information and the clear determination of researchers in their work show that cybersecurity will be subject to important changes in the near future, and a new standard of security will be defined.

## 4. The impact on industries

Today, data about the future of quantum computers is rather theory-based. Although, many researchers claim that the implementation of future fully capable QC will bring changes in a large set of industries. According to research at BCG, 2021, by 2040, quantum computing will have unlocked new markets that will create $850 billion value per year. This amount is a little

less than the value generated in the pharmaceutical wholesaling in the US in 2021 (IBISWorld, 2021). Therefore, the hypothesis that will be analyzed is

> *H2: Quantum computers will greatly transform industry value chains into more sustainable ones.*

With a technology that brings a leap in optimization calculation, product breakthroughs can be expected in experimenting-simulations and more. Accordingly, industries that could make important use of such technology are chemistry, finance, AI, and materials science, enabling them accelerated market share gains and greater profitability, as shown in a report by IBM Corporation in 2018. The future implementations of these machines, when imagining the use cases, will also be able to bring optimization in improving air-traffic controls, ending up with potentially less futile emissions (IBM, 2018) or in capturing CO2 in chemical factories all around the world to have more methods of recycling materials to strive for a more sustainable future (World Economic Forum, 2021). The number of use-cases on how this technology can help optimise businesses that today are far from being sustainable, bringing new solutions to issues that classical computers would need centuries to solve.

## 5. A new technology, an according business model

Calling a quantum computer a "computer" is rather wrong, since it differs in almost every aspect when compared to a classical computer. The technology behind relies on quantum mechanics, a fairly new scope of technology. This means that today material for development is relatively scarce and expensive. Correspondingly, the following question arises: what is the best model to follow to make the quantum industry bloom?

*H3: Experimentation is the only business model to be used for the quantum computer markets*

The industry of quantum computers is young and is far from being fully discovered and its market even more. (Williams, 2021). Hence, according to the theoretical framework presented by McDonald & Eisenhardt, 2020, a nascent market makes it difficult for companies operating in it to follow a defined script. Research shows that experimentation promotes flexibility and learning in uncertain environments (Rindova and Kotha, 2001; Chen et al., 2010). This implies that new firms operating in the current and future industry of quantum computing should make use of experimentation to be successful in commercializing but also developing the quantum technology. Ultimately, it is important to identify a "potentially correct" business model for a market, not only to identify future industry leaders but also to get insights on how to autonomously start a business in this field.

## 6. A new space race?

*"That's one small step for man, one giant leap for mankind."*

This is what Neil Armstrong's first words were when he made his first step on the moon. That moment in history is known to be the peak of the most famous 20th-century competition between the USSR and the US, commonly called the "space race". At that time, between $4.8 and $10.1 billion for the USSR and $30 billion for the US were spent to be the first ones to touch the moon's surface (Asif, 2003; Harford, 1997). Such tremendously high investments brought to light revolutionary technology such as scratch-resistant lenses, solar cells, water filtration, wireless headsets, workout machines, LEDs, and many more (Green, 2019).

Considering that the majority of these inventions launched in the US, a positive correlation between government funding and technological advancement could be possible.

*H4: Governmental funding is a predictor for future leading players in the quantum industry.*

The current situation concerning quantum technology can be compared to the space race. Accordingly, in both scenarios, the world's largest economic forces strive for who will get the most advanced technology first, the only difference is that now more nations are participating in the competition. As of now, it can be reasonable to think that the US won the space race because of the highest funding. Currently, the estimated funding concerning quantum technology is $323 million for Russia, $1 billion for the US, $2.4 billion for Germany, and $10 billion for China (GlobalTech Outlook, 2021). If the hypothesis was "Funding as a predictor for current leading players", it would have already been proven, since up to this date, China issued more than 3,000 patents and currently display "quantum primacy" over other quantum machines such as Google's. Research shows that the Chinese quantum computer outperformed IBM's most powerful supercomputer Summit completing a sampling task in 1.2 hours instead of 8.2 years. Additionally, Chinese engineers also developed a second quantum machine that is claimed to solve Gaussian boson sampling problems 10^24 times quicker than average supercomputers (Zhong et al., 2020). Conclusively, it is noticeably hard to make such predictions, but currently, alternative forms of prognosis are even more difficult to detect.

## 7. The case at ID Quantique

ID Quantique was founded by Professor Nicolas Gisin and CEO Gregoire Ribordy in 2001 in Geneva, Switzerland (IDQuantique, 2018). This firm is a quantum-safe network encryption provider and mainly commercializes optical instrumentation products such as the single-photon detector, which is used to build towards a photonic quantum computer, a quantum machine that makes use of light to process its information. ID Quantique uses these marketable technologies as commodity items and tries to sell them to others that are trying to innovate. Such an approach is good for the context of IDQuantique since they can stay close to their technical area of expertise and invest all resources to push that bound of that technology as far as it can go.

As mentioned in an earlier stage in this essay, cybersecurity will be impacted by the increasing spotlight on quantum technology. ID Quantique tackles this phenomenon perfectly. Over the variety of products they provide, the most successful one is the Quantum Key Distributor, which they developed since the beginning. This accessory to quantum computers enables a much higher degree of security that can potentially set the new standard of security in a future where traditional cryptography systems will be obsolete, as mentioned in hypothesis 1.

Another high-profitable product of ID Quantique is the photon detector that can be implemented in many scientific fields. Partners like QLM make use of these detectors to detect better than anyone else on the planet polluting molecules such as methane, carbon dioxide, and more. This shows that companies like IDQ are creating new industries of scientific application to better tackle the problem of global warming and air pollution, therefore proving hypothesis 2.

The development of the few machines that ID Quantique manufactures has been endless since the very beginning in 2001. As mentioned in an interview with the founders, experimentation, and testing is crucial for a company like IDQ, since they decided to operate in an extremely novice market and industry. Hence, it shows that hypothesis 3 can be proven since experimentation is crucial for such markets.

Lastly, this enterprise cannot be correlated to hypothesis 4, since governmental funding in Switzerland is not significant in the field of quantum computing. Although, IDQ, just like other businesses in the same area, represent important innovation opportunities for large firms that possess and make use of quantum computers. Conclusively, IDQ can represent an important innovation in the fields that the research and discoveries in the world of quantum computing will enable.

**Conclusion**

This essay aimed at giving an overview of important phenomena that are recognizable today. It focused on demonstrating that the rise of quantum technology is of major importance for almost every sector of entrepreneurship and will bring changes in most industries. It is recommended to further discover this field to enable a larger number of use-cases that this technology will allow. The fact that this technology is far from being feasible to develop autonomically does not imply that “catching the wave” of this innovation is impossible. Just like ID Quantique and many hundred firms, also small-sized technology enterprises can enter the competition to develop and manufacture the technologies that are and will be discovered thanks to the new race of quantum computing. In conclusion, it is fundamental to be able to tackle the changes that this technology will carry along with itself, to be able to minimize its threats and maximize its disruptive benefits that can be brought to future society.

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