Department of Commerce
National Institute of Standards and Technology (NIST)

Response to Request for Information on Quantum Information Science and the Needs of U.S. Industry

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Prepared by:

KawlpoQ
9490 Virginia Center Blvd. #332
Vienna, VA 22181
Phone: (703) 255-2189
Email: kawlpoq@gmail.com

Point of Contact:
Debabrata Ghoshal
Email: deb.ghoshal@gmail.com

Submitted to:

Department of Commerce
National Institute of Standards and Technology
Attn: Dr. Claire Cramer
claire.cramer@nist.gov

1. About KawlpoQ

KawlpoQ is a recent start-up company that performs research and development in Quantum Information Science (QIS) and data-oriented applications. The primary focus of this company is to leverage the ideas and concepts gained by QIS to solve practical problems related to data that can be solved using quantum algorithms. We are also investigating ways to produce quantum software to perform simulations of quantum physics using quantum walks, the other model of quantum algorithms.

KawlpoQ has strong ties with iWorks Corporation (www.iworkscorp.com) to handle federal contracts. Together, KawlpoQ and iWorks can provide the necessary products and services.

KawlpoQ is pleased to answer the questions posed by the Department of Commerce, National Institute of Standards and Technology (NIST).

2. Quantum Information Science and the Needs of the U.S. Industry

2.1 Opportunities

QIS is a growing field that encompasses many areas of research. Some of the most common areas are quantum computing and processing, quantum algorithms and programming languages, quantum communications, quantum sensors, quantum devices, single photon sources, and detectors.

2.1.1 What areas of pre-competitive QIS research and development appear most promising?

QIS research and development appear promising in all of the areas named above.

The following are several research projects that are very promising:

- Superconductivity, Topological Quantum Computing, Ion Trap, and Spintronics are very promising research and development in building quantum computers.
- Research and development in Quantum Communications is very promising. For example, research in Cryptography has advanced to a high degree and is still continuing.
- Quantum Algorithms, and Search and Number Theoretic approaches have shown good progress in research and development. Research on high level Quantum Programming Language is also on-going.
- Applications of concepts of Quantum Mechanics (Superposition, Entanglement, Teleportation etc.) are another promising area of research and development. These applications include quantum sensors, quantum devices, single photon sources, and detectors.
- Machine Learning, Big Data and Graphics Processing Unit (GPU) are some fields of research where we are expecting some encouraging results.

Of all the promising research and development areas, the most promising pre-competitive research areas are the applications and devices ("Superposition," "Entanglement," "Teleportation," and "Decoherence" centric applications and devices) that include quantum sensors, quantum devices, single photon sources, and detectors. Quantum Simulator, where a particular quantum controllable device or system can investigate the behavior of another quantum system, has made significant progress. By controlling a single photon, researchers are advancing their knowledge to do the tasks of artificial intelligence to a much higher degree. Again, Quantum Simulator is one of the best examples of a quantum device research product.

2.1.2 What areas should be the highest priorities for Federal investment?

Federal investment is a great help to the pre-competitive research and development areas. It is important to remember that real help is needed to remove the barriers to improvement. In QIS, federal money should be invested to those who have been struggling financially to improve their product, service or applications to a much higher level. To set priorities, the federal authority should evaluate first an applicant's plan and program and how they can remove their barriers with federal money.

At this time, it appears that the highest priorities of QIS should be given to those who are producing results and showing good progress in building quantum computers, which can be easily scalable. This is from the hardware side. From the software side, the highest priority should go to those who have a good plan to provide a "Killer App," i.e. an application that becomes very popular in a short amount of time.

Money should also be invested into enhancing QIS education to all concerned people. Another important area of help should be given to QIS consulting services. These services initially help to evaluate the problems of industry where QIS is appropriate and then recommend how to investigate the solution using quantum methods and quantum hardware.

Lastly, but not the least, federal money should be invested into research where quantum methods may challenge the Big Data oriented problems and improve the computing process with higher speed and efficiency.

2.1.3 What are the emerging frontiers?

The frontiers or the unexplored areas of QIS where new insights are developing are

- Chemistry
- Biology
- Financial
- Software Development
- Data Analytics
- Games

- Image Processing
- Quantum Network and Quantum Internet

Please see the Appendix for relevant references, such as general articles or short explanations for each area.

2.1.4 What methods of monitoring new developments are most effective?

There are a few methods of monitoring new developments as practiced by different organizations. For example, periodically checking how the policies and procedures of the organization are followed by the vendors, or frequently monitoring their performance. However, for new developments in QIS the most effective method would be to communicate back and forth with the vendor after each step of the process or in between the processes. These communications should clarify the details of expectation from the monitoring organization as well as any misconceptions or lack of understanding of the vendor or contractor. Depending on the nature of development, these channels of communication should cover the aspect of the method of monitoring. The channel could be on-site monitoring, report writing or a contingency plan in case of a vendor's failure to provide the necessary product or output.

2.2 Market Areas and Applications

There are several market areas of QIS where federal investment has already made an impact. There should be new market areas for QIS and we should gather information about that market.

2.2.1 What market areas do you think would most benefit from quantum information science?

Market areas where Quantum Measurement is used are Quantum Sensors and Quantum Precision Components. These markets would benefit most from QIS. Quantum Clock, GPS systems and different quantum optic sensors and devices etc. are some products of this market area.

Quantum Telecommunication is the next area where the market is already growing. Quantum Cryptography is one special area of this industry.

Quantum Computing and Quantum algorithms are part of the area where QIS would have a large potential market, depending on how long it will take to build a practical universal quantum computer. However, once it starts, there would be a tremendous impact on the market of QIS. It will be similar to the classical computer software market – markets for building software development tools, operating systems or different high-level languages and applications.

The financial market is another area where there is a lot of potential for quantum information to play a major role.

There are a few other associated sectors in biology, chemistry and energy solutions where the market would benefit from the research and development of QIS progress.

2.3 Barriers

Appropriate funding is necessary to improve any area of QIS, and to remove barriers to QIS research and development growth.

2.3.1 What do you see as the greatest barriers to advancing important near-term and future applications of QIS?

The greatest barrier to adoption of QIS technology at this point in time seems to be the lack of communication between the different parties of the quantum science/technology researchers and business communities. Any new industry requires the involvement of many parties. There are innovators as well as investors, individuals as well as business groups, technological experts as well as marketing/business experts, etc. It takes time and effort to organize and discipline a critical mass of people to develop a new industry/technology and make it a popular one. To advance the near-term and future applications of QIS, different groups need to come together and execute a common plan under a common platform with specific goals in mind. For example, the different groups could produce a specific product following a strict schedule and market it accordingly. This collaboration is the hardest part, which is why it is the greatest barrier to advancing at this point. Some government initiative is required here and that would certainly make a big difference in the long run.

Other barriers are described in our response to the following question.

2.3.2 What should be done to address these barriers?

To address the most important barrier as stated above, initially we need an organization where all participating members could exchange ideas and concepts relating to their requirements. The main motivation of such an organization is to translate all of the exciting QIS research results from the universities and industry in a common language to the media, business community and entrepreneurs.

To address other related barriers, several issues should be seriously taken into consideration and make efforts to improve:

- Investments in innovation
- Appropriate funding (dollar amount) to reduce financial risk
- Appropriate timing of funding to reduce technological risk, evaluating dependent technologies and allocating funds for them in future
- Companies should find out how they can be profitable using the new technologies
- Academia should find out how to have a good potential market

2.4 Workforce Needs

As an emerging industry, we need to know about the knowledge and skills required for QIS and related technology.

2.4.1 What knowledge and skills are most important for a workforce capable of addressing the opportunities and barriers?

Knowledge of Quantum Mechanics, Computer Science and Information Theory are most essential for the workforce to address opportunities and barriers in QIS. The skills of marketing new products in a very new industry or business, material management at the atomic level, and good communication are also part and parcel of the workforce of QIS.

2.4.2 In what areas is the current workforce strong, and in what areas is it weak?

There are a vast number of people engaged in various fields who have the background and required skills and experience of computers and Computer Science. They would be helpful for new QIS work; however, they lack the knowledge of Quantum Mechanics and Physics. On the other hand, there are individuals who have a solid understanding of Quantum Mechanics and Physics but they do not know the basics of Computer Science or Information Theory, and are not fit to work in this very new industry.

2.4.3 What are the best mechanisms for equipping workers with the needed knowledge and skills?

The best mechanism for equipping workers is, as always, proper training. Through different workshops, seminars, or training schools we can provide training for the immediate need but for the future growth of QIS, we really need a disciplined study in colleges and universities. Under the subject of "Quantum Information Science," different schools may place emphasis on the special field of QIS to produce specialists in that area.

The other mechanism to equip trained workers is through consulting services where experienced science teachers or mentors would work with technology and business professionals to train the workers. These services should also train the workers to evaluate any problem that is appropriate for QIS investigation or not.

Appendix I: References

The following are several resources for more information on emerging frontiers in QIS:

1. Chemistry and QIS: The following article provides good information about the emerging frontier in Quantum Computing in Chemistry:

https://mycqstate.wordpress.com/2012/12/16/theory-and-beyond-quantum-computing-for-chemistry-applications/

2. Biology and QIS: This is the article which explain the dawn of new field quantum biology

http://www.nature.com/news/2011/110615/full/474272a.html

3. Financial and QIS: A short article related to Stock Market and Quantum Computing

http://finance.yahoo.com/news/decoding-stock-market-quantum-computers-200146816.html

A feature in Wall Street:

http://www.waterstechnology.com/waters/feature/2111500/feature-wall-street-ready-quantum-computing

4. QIS and Software Development: Breakthrough of Canadian Companies in the emerging market: claim to have applications in the financial and software tool development, simulation markets.

http://1qbit.com/

http://artiste-qb.net/wp/application/

5. QIS and Data Analytics: Breakthrough of a U.S. Company in a new market of Data Analytics and quantum computing.

http://www.qxbranch.com/blog.html

6. QIS and Games: A very exciting frontier where there is potential to have many breakthroughs. A Quantum Game Theory is explained here:

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.105.1489&rep=rep1&type=pdf

7. QIS and Image Processing: A good understanding of the concepts behind Quantum Image Processing is in the chapter 8 of this link:

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.105.1489&rep=rep1&type=pdf

The following is a good introduction to Quantum Computer Graphics (subscription with ACM is required to get the article):

http://dl.acm.org/citation.cfm?id=1198722

8. The following is an overview of QIS and Quantum Network and Internet:

http://www.thequantumnetwork.org/research/

One can get some good information about quantum internet here:

http://www.technologyreview.com/view/514581/government-lab-reveals-quantum-internet-operated-continuously-for-over-two-years/