NATIONAL ROADMAP 2020-2029

THAILAND QUANTUM TECHNOLOGY

Roadmap for Quantum Technology Development in Thailand 2020 - 2029

February 20, 2020

Ministry of Higher Education, Science, Research and Innovation

executive summary

Quantum technology is the application of the principles of quantum physics to measurement (metrology), computation, processing, encryption, transmission and storage of data with greater efficiency and potential than the classical method.) new generation of quantum technology quantum technology generation 2 (QT2) is based on the ability to precisely control quantum conditions. as a result of the advancement of technology This makes the above operations faster, safer, more stable and more accurate. Quantum technology can be divided into four main areas: (1) quantum computation (2) quantum simulation (3) quantum communication. (quantum communication) and (4) quantum metrology and sensing, all of which are rapidly developing. It has become an emerging technology that directly affects business and daily life. Quantum technology is therefore often It is mentioned as a disruptive technology that could revolutionize economic, industrial and social development again in the near future. this technology greatly This can be seen from the enormous amount of research funding invested. and the development of manpower in this field continually Every country will be influenced by the development of new age quantum technology, the impact will be more or less in the direction that supports or inhibits the development of that country. It depends on the readiness and potential of each country. quantum technology It could be called a double-edged sword. If any country is ready and has the potential to

use it It will give you enormous meanwhile Unavailability or inability to use this quantum technology. would cause the country to be at a competitive disadvantage business is very and destroy the stability of the country.

The impact of quantum technology on Thailand

The new generation of quantum technology is in its early stages of development but is developing rapidly, Thailand needs to prepare for national security. and create opportunities for themselves as some manufacturers of this technology to increase economic competitiveness Especially the development of new industries in the country. In summary, the following technologies, the new quantum era, will affect the country in various ways.

1) Security Quantum technology strengthens national security in terms of information security, whether it is military information or national strategy. and business information Including raising the level of privacy protection (privacy amplification) in both communications banking and Internet transactions because quantum communication can protect the confidentiality of information through quantum encryption that cannot be stolen.

On the other hand, the absence or use of quantum technology will put the country at high risk of data theft and may not be able to join a communications network with an organization that uses quantum technology for treatment data security because those who do not have quantum technology will be regarded as the weakness of the security of the network that can can be used as a data theft point Without quantum technology to preserve information Daily transactions such as internet access and money transfers are not safe. Because today's encryption can be hacked (hack) easily with a machine. quantum computer

2) Economically, quantum technology will be a new technology that has a very high price when it comes to use. At the same time it is also It is a technology that is being developed. Thailand can be a producer of some quantum technology because quantum technology is diverse in 4 main areas and applications. make thailand able to create their own product or technology in any dimension of this technology which will be the basis important in the development of the country's industry in the future Currently, quantum technology is still in its early stages, giving Thailand a high opportunity to become a producer. This will increase the ability to compete in business and reduce disadvantages in the trade balance in the future. that Thailand is not ready or

unable to develop their own quantum technology In addition to being a buyer this technology in the future May lose the opportunity to invest in foreign companies. because of the availability of technology Quantum will be a key factor in attracting capital. and human resources into the country the absence of quantum technology should cause Thailand to lose business opportunities and human resources to other countries that are ready and support

The development of quantum technology

3) public health Application of quantum technology in medicine will improve the quality of life of the people Because quantum technology will be the basis for inventing medical diagnostics that can measure and Accurate and fast analysis In addition, quantum computing technology will help process information. fast medical This will help to develop the right medicine for the disease in a much shorter time. This will reduce costs, which will result in people having access to medical treatment on time and not paying too much expensive medicine. that quantum technology can Faster analysis of patient genetic data make this service more accessible to more people and taken care of health that is suitable for oneself individually Applications of quantum technology in medicine have already occurred in many countries, including Thailand, in the form of advanced tools such as magnetic resonance imaging (MRI), but there is still much to be developed. Especially making measurements (sensors) with high resolution. If Thailand does not develop its own quantum

measurement technology for medicine will continue to lose trade balance and lose the opportunity to create medical devices that directly correspond to the context of Thailand, such as the invention of medicines or methods for treating tropical diseases

4) Socially, quantum technology will change people's lifestyles. and reduce inequality in society, in addition to increasing business opportunities application of quantum technology to solve various problems in the context of Thailand, such as traffic problems water management problems will improve the quality of life of the people If Thailand is a manufacturer this technology People will be able to access more. to reduce inequality in society, for example, farmers can use The right quantum technology to increase agricultural productivity or obtaining health services that are suitable for themselves. In addition, quantum technology will open up the science of learning in new sciences and create a career path (career path) that the new generation can access. and create a variety of careers such as Quantum language programmers or quantum network administrators, it is predicted that as quantum technology advances to a certain extent, the development of robotics will follow by leaps and bounds. make our way of life change This may cause some occupations to lose importance, such as bank officers. But at the same time, it will reduce social ingenuity, for example, robots can learn to drive. And communicate with the GPS system (GPS) quickly and highly accurate. Including having a measurement system that is only ready to make people with disabilities (even visually impaired) able to drive like normal people

5) In education, quantum technology will stimulate deep science learning, not ignorance, and skill development. the thinking process of learners to have high potential This will result in Thai society becoming a more rational society. and use the principle More scientific reasons for living Quantum technology has enabled the development of education. linked to standards of the world community Resulting in an incentive to raise the level of education in Thailand to a higher quality. allow students See what career paths are like in your own interests.

6) Environment How Quantum Technology Makes Operations More Efficient make time for less processing This will directly result in energy conservation. and indirectly affecting the conservation of the environment In addition, the application of quantum technology to solve environmental problems such as quantum computers can be used. Predict the effects of chemicals on global warming faster and more accurately in a shorter time. This results in planning the use of chemicals or other resources with higher goals and efficiency. One of the major problems in the world right now is the process of fertilizer synthesis. which takes a lot of time and energy Computational technology or quantum simulation will have Great benefit in improving the fertilizer production process. to save energy Reduce waste and pollution to the environment. ***7) Cooperation with the world community.*** Quantum technology will not only provide communication security, but will also enable cooperation between international organizations. Due to the wide variety of quantum technologies, it is not possible for one country to own all of the quantum technologies solely. cooperation at scale International education will enhance education and increase economic opportunities as well. Moreover, the quantum technology in the As a metrology it is necessary to be recognized internationally. (international certification), which Thailand can play a leading role (key player) in setting standards in metrology

which will bring pride and global visibility. And it is necessary for effective international communication such as 5G and 6G communications, the use of global navigation satellite system (GNSS).

In summary, Thailand must be prepared to support the country's development in the era of quantum technology. develop rapidly and need to develop some quantum technologies of their own for specific solutions Thailand's context, such as increasing agricultural productivity design of traffic networks for maximum efficiency; drug design and synthesis for tropical diseases; Moreover Quantum technology is still in development, but not perfect. It gives Thailand the opportunity to create some quantum technology on its own. Create a product that is the country's technology to enhance the capabilities of both the industry and the supply chain cycle Thailand should not miss the opportunity to create The technology itself this time was like it had missed opportunities in the past because of being unprepared. Quantum technology is a

world-changing technology at a high price. And it requires specialized experts to operate. Therefore, it is necessary to develop appropriate manpower to support this technology. In addition, some quantum technologies, such as encryption devices, It is necessary to have a certified organization to be able to trade. or transferable because it affects network stability Therefore, Thailand needs to have the potential and readiness to operate in this field, developing manpower, directly involved organizations. And the infrastructure for quantum technology is therefore a necessity for countries that must be done in conjunction with research to develop technology

Opportunities and challenges for Thailand

Thailand has always been an agricultural country. and will continue to be so But how to make the agricultural sector Thailand is based on technology that increases productivity with high efficiency. and to have a good quality of life. In addition, Thailand also It needs to have its own industry that can be a source of income for the country in addition to agriculture, services and tourism. The development of quantum technology for Thailand is very challenging. Both technical challenges in inventing, designing and producing parts that can use quantum technology. Creating new technologies is extremely challenging. Because as a country, we have never had experience in this field before. The challenge is multiplied when attitudes are taken into account. and readiness of the people of the country Thailand has missed the opportunity to own technology many times in the past.

Because quantum technology is still in its early stages of development. and has a variety of complexity dimensions And its application gives Thailand the opportunity to own this technology. (Partly suitable for Thailand) which will have an impact on many dimensions of the country's development as analyzed above. Therefore, it is considered an important and urgent agenda for Thailand to plan and implement the development of quantum technology. systematically, both in the preparation of manpower

to support the development of this technology Infrastructure preparation for national security and research for Develop industrial and commercial prototypes. Another important opportunity in the

development of quantum technology. Is to create a career path for the next generation to pull

provide the potential of the people in the country and attract capital and foreign researchers to help develop our country

Thailand's Quantum Technology Development Plan 2020 - 2029

Ministry of Higher Education Science, Research and Innovation (QU.), therefore, proposed a Thailand Quantum Technology Roadmap (TQTR) development plan for the next 10 years, summarizing the development plan. The country's quantum technology is schematically depicted in Figure 1.

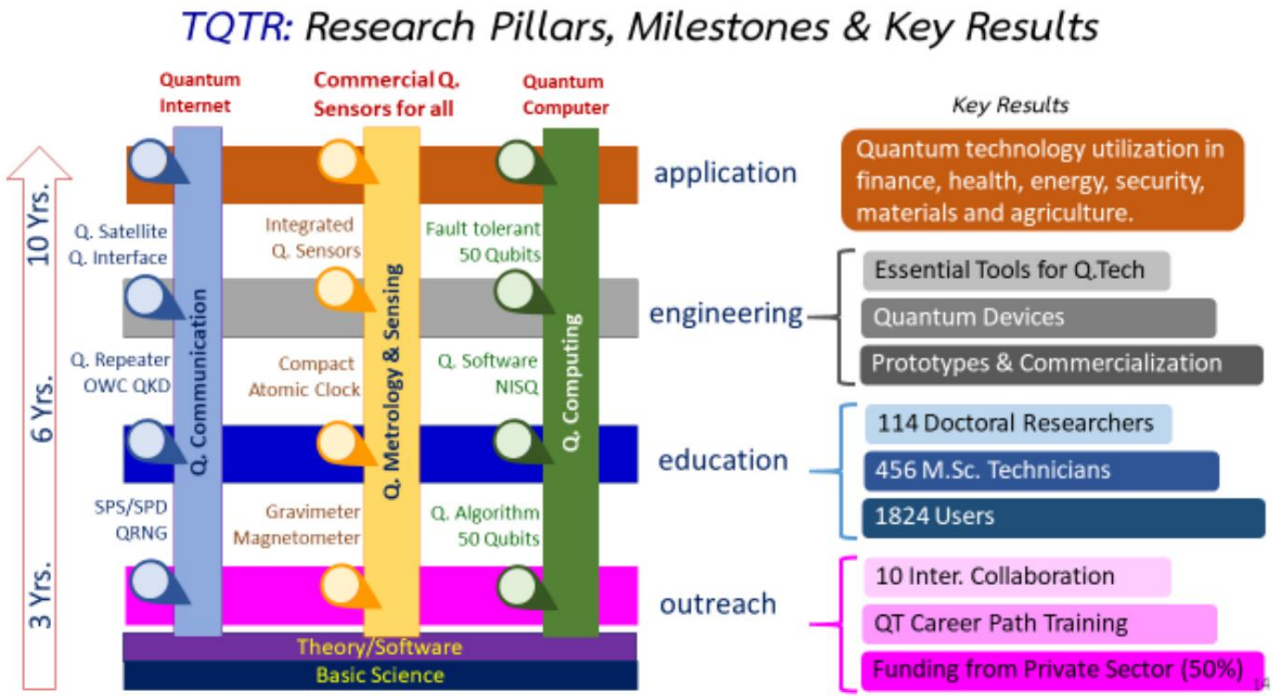


Figure 1. An integrated diagram showing the pillars, boosters, and expected outcomes for the development of quantum technologies. Thailand between 2020 and 2029

Quantum technology in Thailand consists of 3 pillars: (1) Quantum Computation and Simulation, (2) Quantum Communication, and (3) Quantum Metrology and Measurement. Compared to international navigation maps, countries

Thailand combines quantum computing and quantum simulation into one pillar. because they will develop together

In addition, Thailand does not have a research group that is large or diverse enough to separate research in the next 10 years.

Each pillar has a goal. and their own navigation map (technical roadmap), such as the main goal of Quantum computing is the creation of a quantum computer. (including algorithms) and the main goal of quantum communication. is to create a quantum internet Along the way, research has to be invented. Or create necessary equipment in various fields, which these developments can be used for commercial purposes (spin off) or creating metrological standards that make Thailand in the at the forefront of the global community

for supporting factors or promoter which includes education (education), public dissemination (outreach), engineering and application of quantum technology It is the creation of an ecosystem (ecosystems) of the technology development plan to be concise. Efficient, stable and sustainable, this technology development plan has predictable results. to see that it will increase the potential or how to help propel Thailand forward

This document is a detailed compilation of Thailand's quantum technology development plan, which includes a guide map of each pillar. Guide map of contributing factors and application of quantum technology expected results and an estimated budget for implementing the said plan for 10 years with the implementation of the said technology development plan. We will lead Thailand towards stability, prosperity and sustainability in the age of quantum technology.

list of contents

Thailand Quantum Technology Roadmap

developing country or countries with unstable economy and society believe that their country is not ready to It will invest in basic research and frontier research as it is an investment. High value and produces results in the short term. therefore aiming to invest in technology from abroad as a tool for development industry and agriculture, believing that it can generate rapid returns. However, the investment model for Such economic development cannot create long-term and sustainable competitiveness, that is to say, the advantages of natural resources are taken only as raw materials. but cannot add value by itself This creates dependency on foreign investment and technology imports to acquire new technologies. This dependence on external experts and technology tends to increase in both value and confidence. lead to instability and Sustainable development in the country as clearly shown today. that the country has a continuous technological deficit of value The ever increasing level of sophistication of technology becomes a burden on the country's fiscal system. Finally, when resources are depleted or wages are rising will no longer be able to attract foreign investment and rely on technology from Externally, it will cost much more than investing in basic and front-line research. (present country Thailand has a technological deficit of more than 200 billion baht per year). There is also the fact that every country that can overcome The middle-income trap to a developed country is a country with its own technology. Such technology can be used as base for economic development society and stability both in the short term and in the long term

At present, the classification of basic research and applied research is becoming unclear. due to emerging knowledge and technology are all rooted in increasingly overlapping research. Therefore, frontier research is directed in the direction that leads to Fundamental advancement beyond the frontier of knowledge, not limited to fundamental research. Applied Research or Industrial Research Therefore, the results obtained from the research phase The front line may be classified according to the above objectives into 3 characteristics as follows: (1) leading to new discovery (2) first in class achievement (3) creating something Good at the world (best in class), which all three types are but transcends all boundaries of knowledge. However, what may help distinguish basic research from advanced research is that goals to meet the challenges that will arise in the future Fundamental research aims at creating new knowledge without mentioning it. goals to meet the challenges of the future While front-line research takes into account response goals. such a challenge History has shown that both types of research are mutually exclusive and interdependent if investments in both groups can be balanced. will cause efficiency in creating new knowledge create new technology and create readiness to meet future challenges

1. What is Quantum Technology? who does what where How Quantum Technology Will Change the World

After quantum theory was developed in the early 20th century, it played a revolutionary role in its development. Technology for applying quantum physics phenomena at the micrometer level or nanometers cause creation The transistor is fundamental to the development of the electronics industry and provides many facilities. in our life such as computers, smart phones medical equipment, etc. Such developments are considered It is the first generation of quantum technology. Or first generation quantum technology, which still uses the group properties of many particles. But it brings enormous benefits, as we can see from the various devices around us.

over the past three decades Great advances in physics and engineering have made it possible to control and use the quantum properties of individual particles. or each state of the particle to create a new generation of quantum technology Or the second generation quantum technology (second generation quantum technology) that has the potential to measure, compute, process, transmit and store data more accurately, quickly and more securely. This technology can be divided divided into main branches, namely Quantum metrology and sensing, quantum computation, quantum simulation, and quantum communication. All of which are technologies that are being developed rapidly. and was expected to become new technology (emerging technology) and disruptive technology that can revolutionize With economic, industrial and social development again in the near future, many companies, organizations and countries are therefore Pay attention to the development of this technology and follow up to prepare accordingly.

Every country will be directly influenced by the development of quantum technology. The impact will be more or less, or in a positive or negative direction, depending on the readiness and potential of each country. Thailand therefore needs to be prepared for the

following main reasons: 1) Quantum technology provides national security in terms of information security. Both in communication, finance, banking and internet

transactions. 2) Quantum technology provides accurate measurements. Necessary to develop other technologies of the country to operate efficiently, such as communication in 5G and 6G systems, use of satellite navigation (GNSS), standardization of time and other

metrological units. 3) Thailand needs to develop its own quantum technology. to solve specific problems in the context of our own country, such as increasing agricultural productivity Optimized Traffic Network Design design and synthesis medicine for tropical diseases

4) Quantum technology is developing rapidly. but not yet complete, giving Thailand an opportunity to build Some quantum technologies have come up on their own. Create the country's own technology products to enhance the capabilities of both

in industry and the supply chain cycle Thailand should not miss the opportunity to create their own technology this time like had missed opportunities in the past due to lack of availability

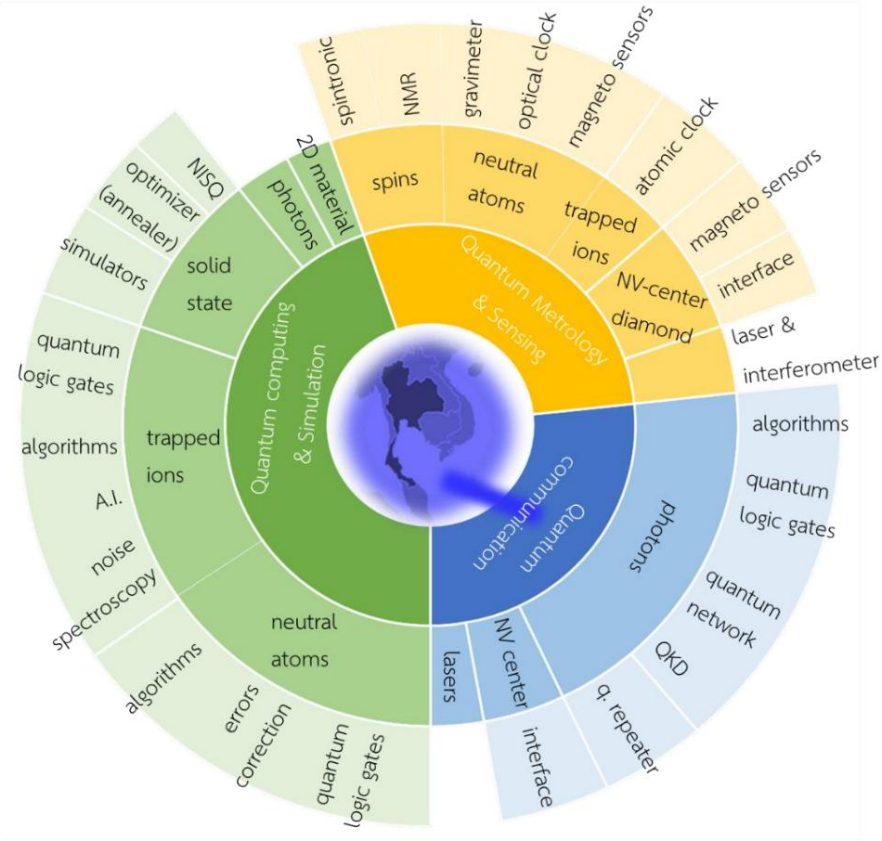


Figure 2 Summary of quantum technology in all 3 pillars to be developed in Thailand.

5) Quantum technology is a disruptive technology that is expensive and requires Specialized experts in operations Therefore, it is necessary to develop manpower suitable to support this technology. such as encryption devices It is necessary to have a certified organization to be able to trade. or can be transferred because it affects the stability of the network Therefore, Thailand needs to have the potential and readiness to Operations in this field, the development of manpower.

directly related organizations and infrastructure for quantum technology. It is therefore necessary for the country

1.1 Relationship with other technologies

The relationship of quantum technology with other technologies may be considered in two perspectives: (1) technology that results from Quantum technology and (2) technologies that help the development or application of quantum technology have higher value. The effects from each pillar of quantum technology may be considered as follows:

1) Technology that results from quantum technology

- Communication technologies such as 5G/6G or GPS or GNSS will benefit from the development of metrology and Quantum Measurement and quantum communication make more accurate measurements In the future, we will have a network A quantum that can safely transmit information and the data transfer rate is much higher let us be able GPS's processing is so accurate that the car can drive automatically.
- Resource Exploration In the future, we may use atomic clocks to measure changes in the gravitational field. has made the geologic conditions more accurate which for Thailand should be very useful in manage water planning Similarly, other quantum metrology results, such as gravimeters that help in exploration of geological resources, or magnetometers that measure magnetism or variability in small magnetic fields, are of high resolution. • Pharmaceutical technology. When Quantum Computers Can Be Programmed

(programmable quantum computers) It will be very useful in many fields. Especially in the medical and pharmaceutical industry. Researchers won't have to spend a lot of time trying to find the right drug structure for a particular disease. quantum computer or a quantum simulator will greatly reduce the time. and will allow Search for more diverse structures. and more efficient Again, there is a high probability that it can be produced. genetically determined drugs Make patients respond effectively to the received drug faster. • Material technology. Materials that can withstand extreme conditions, such as extreme pressure or extreme heat load, are difficult to predict and synthesize today.

Quantum computing technology will enable faster and more accurate characterization of materials, which will be of great use in the construction of nuclear fusion reactors. Or create a research station in space. • Financial technology. Quantum computing and communication will enable transactions. (Transactions) in finance via the Internet is safer and can separate the time sequence (time stamp) of transactions in detail, which will greatly affect the

investment in the stock market. In addition, software development For quantum computing, a variety of predictive models are possible. and higher accuracy in investment account adjustment (portfolio optimization) to be more in line with current market conditions

- Calculation technology which consists of writing algorithms or the use of artificial intelligence (AI). Both will benefit directly from developing quantum-based algorithms. (quantum-assisted algorithms) and artificial intelligence has fast progress and will be an important part of our lives

2) Technology that enables the development of quantum technology

Because quantum technology is still in its early stages of development. It therefore needs to use other technology to help it. can develop faster In summary, it is Controlling quantum states is another subtle matter, which may require the use of electronics. Engineering, fabrication and control with unprecedented precision and detail. These technologies were created to make quantum technologies work, to take advantage of quantum principles and states. In addition, the use of artificial intelligence to help make decisions in choosing best fit or to predict the behavior of a quantum system in advance

1.2 Threats and opportunities

having quantum technology Or can be developed into a country will have a positive effect on the country highly giving the country the opportunity to investment business competition It attracts new industries to invest in Thailand. As well as it will increase the main productivity. of the country from agriculture and including other dimensions that quantum technology affects Thailand that quantum technology still It is in the early stages of development. and has a variety of complexity dimensions and its application has made Thailand Opportunity to own this technology and be able to systematically plan and implement the development of quantum technology both in As for the preparation of manpower to support the development of this technology, preparing the infrastructure for national security and research to develop industrial and commercial prototypes. Another important opportunity in the development of quantum technology is to create a career path for the next generation to bring out the potential of the people in the country. And attracting funding sources and researchers to help develop our country.

If Thailand does not have quantum technology It will make the country vulnerable to threats of data theft, including information at the national security level. and personal information of the public Internet transactions are highly risky. and greatly reduced credibility. This will affect participation in international communication networks as well. All this does not count. Thailand will lose the opportunity to develop the country with the benefits of quantum technology mentioned above, or at least cause Thailand to fall behind other countries, thus losing the opportunity to attract investors. and may cause problems Loss of human resources or potential to other countries (brain drain).

2. Vision and Strategic *Direction*

2.1 Goals for 10 years for Thailand

1) Put Thailand in the top 5 of Asia in quantum research. and is a leader in the ASEAN region that can Attract researchers and investors to Thailand. 2)

Increase the country's competitiveness. 3) Use quantum technology to develop and solve problems specific to the context of Thailand, such as weather forecasting water management solutions solving traffic and transportation problems Reducing the

time to invent and produce drugs for Tropical diseases including new materials

4) Build an infrastructure to prepare Thailand to support the development of the economy and society in the age of quantum technology. especially the security of information and communication systems If

looking at building infrastructure and country development We may summarize the goals of technology development. Thailand's quantum can be divided into 4 levels as follows:

Figure 3 shows a 4-step plan for the development of quantum technology in Thailand.

2.2 *Guidelines for achieving the goals*

The development of Thailand's quantum technology takes time. and systematic long-term planning, but at the same time, it must be started immediately for Thailand to have the opportunity to create their own technology in some topics quantum technology The important thing is to lay a solid foundation for development. Sustainable in all dimensions, both in terms of educational development. and manpower building Along with accelerating research output at an international level 1) Building a network of quantum technology researchers to work in a coherent way and have a common goal. to drive research

In terms of quantum technology, it can support quantum technology that is being developed rapidly. 2) Create a curriculum. Plan and develop highly specialized and skilled manpower for research and development.

3) Provide basic knowledge and awareness of the importance of new generation quantum technology to the youth and the public. general

4) Ongoing research funding from government and private sectors 5) Building international collaboration That is strong and conducive to the development of quantum technology in Thailand to have potential in competition

6) Accelerate the production of international research projects that specialize in certain dimensions or research topics of quantum technology.

Things to be accomplished during the first 3 **years of the initiative (Initiative Phase: 3 years)**

1) Research projects that indicate the potential of the research team. and is a project that has a high impact on the development of science and A national economy (about 10 projects) where researchers work together as a clear team. and can evaluate 2) establishing a mechanism to drive specific research after the initiative phase aimed at scientific development or

3) long-term planning for what the country needs to support the development of quantum technology, even if it is not Aimed at research But it is a fundamental factor that the country must have.

4) At least 100 researchers in the network 5) 30 master's or doctorate graduates specializing in quantum technology 6) Network of research teams, policies and strategies to drive research in quantum technology m

2.3 Objectives and Key Results According to the 4-step plan (Figure 3) in the development of quantum technology in Thailand, which are (1) preparation (2) practical demonstration (3) Knowledge development (4) Creation of some innovations for the country's industry We can write an analysis as an objective (objective) and key results (key results) in a period of 10 years as follows:

Goals (objectives) 1. Prepare	**Key results** 1.1 Create systematic learning
and develop the capabilities of Countries in quantum technology to support The new era of quantum technology is coming.	activities for young people And the general public 1.2 Train users to have knowledge and skills necessary for quantum technology 1.3 Build personnel to support quantum technology through courses and training 1.4 Be a partner in research and development projects Important quantum technologies of the
2. Apply quantum technology to develop and Solve problems specific to the context of Thailand, such as increasing agricultural productivity. logistics solution water management solutions shortening the time invention and production of medicines for tropical diseases, including to new materials.	world 2.1 Demonstrate the use of technology in Solve specific problems in the Thai context. 2.2 Get a process that solves some problems of country
3. Increase the country's competitiveness. by building knowledge Intellectual property and innovation and technology of specific countries can be developed into a new industry in the country for the ability to compete in business and investment and reduce the trade deficit	3.1 Joint research projects with specialized research institutes the world through a network of international cooperation At least 3 projects. 3.2 Research articles published in academic journals with an impact factor of not less than 50 issues. Commerce and Standard Development, not less than 5 performance 3.4 To be a leader in quantum technology in ASEAN countries and in the Top 5 of Asia.

Objectives 4. Create an	**key results**
infrastructure for preparation	4.1 Research and research teams with excellence
of Thailand to support the development	Academics can be the origin and developer.
Economy and Society in the Age of Quantum	quantum technology
Technology especially in terms of data security and communication system	4.2 Infrastructure for Quantum Technology

for important results on the way to achieve the objectives and achieve the intended results can be summarized as

The diagram is as follows.

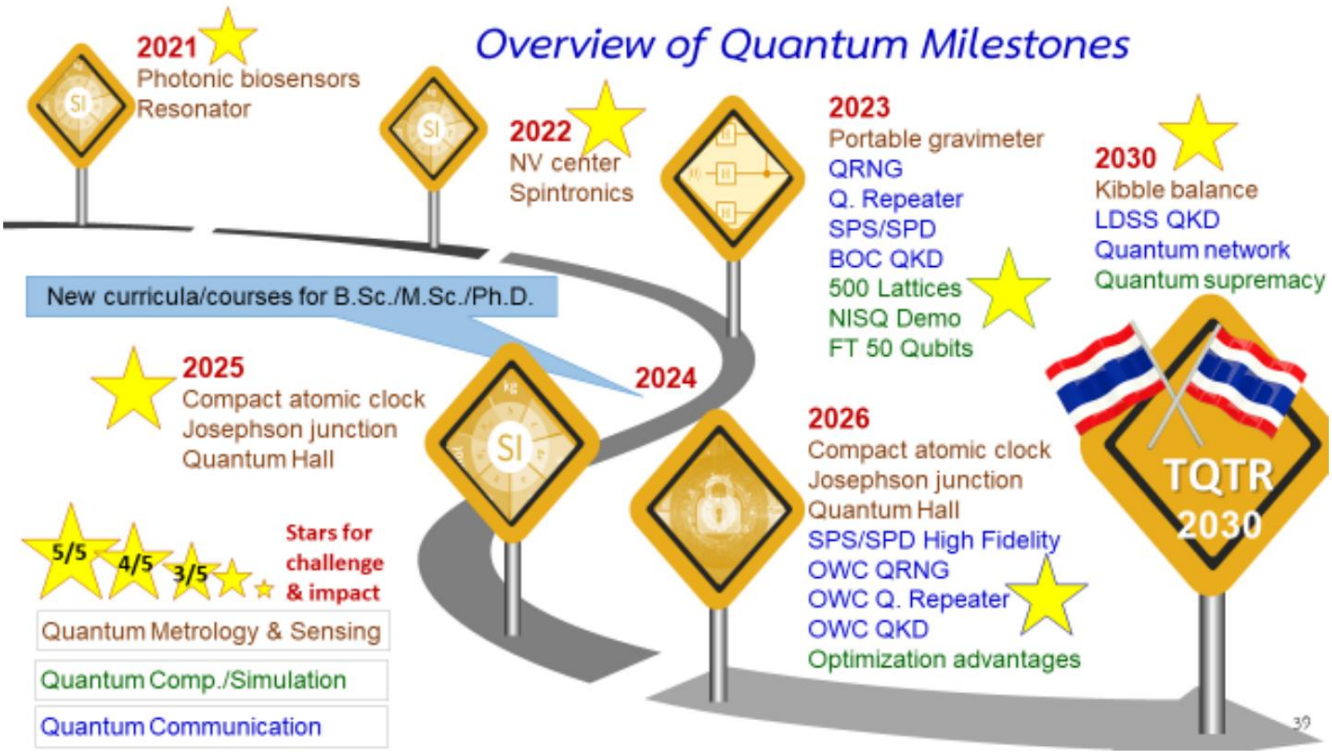


Figure 4. An overview diagram of milestones over the past 10 years of quantum technology to be developed in Thailand. The diagram does not show the number of published works (average 5 per year) and number of students produced (average 57 per year).

graduate level)

3. Pillars ***of Quantum*** **Technology** Thailand lags far behind internationally in

new generation quantum technology (QT2.0) in terms of manpower, research capital, and knowledge in technology development. Thailand's quantum needs to prepare the country to have The fundamental elements required in all four fields of quantum technology are quantum computing, quantum simulation, quantum communication, and quantum metrology and measurement. In addition, Thailand also needs to create Expertise in internationally competitive research topics for further development into industry and driving the future economy Each field of quantum technology requires planning in terms of manpower, research and innovation. which may take different periods of time They must set goals and create a clear road map.

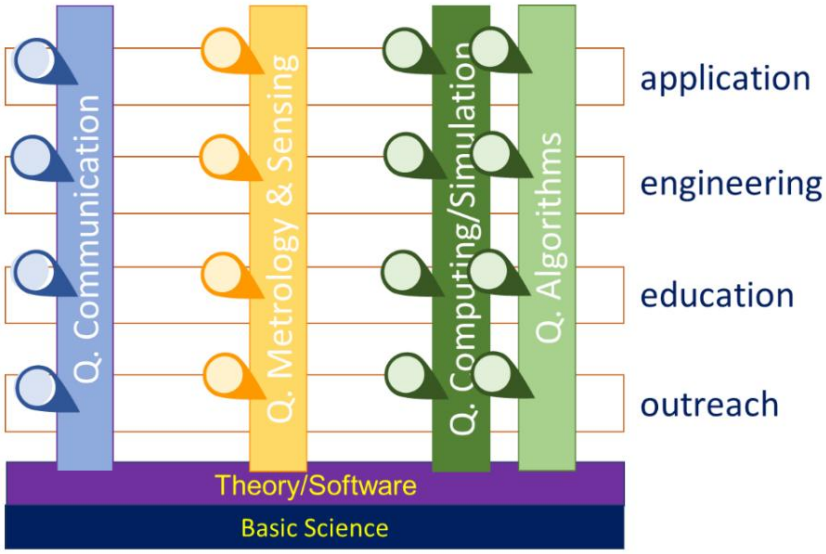


Fig. 5 Pillars of quantum technology in Thailand Quantum algorithms are part of computing and Quantum simulations can have their own roadmaps and milestones as development timeframes may be. Unlike other pillars, theoretical studies and software (theory/software) is a high-level basic knowledge that is used in action or control quantum systems for quantum technology

The development of quantum technology in Thailand It combines the fields of quantum computing and simulation. quantum together as one pillar because there are similar research characteristics Although they have different goals, but May be separated into hardware development and software development or algorithms because of different time frames and availability. In each field of quantum technology, it is necessary to

plan research development along with laying the foundation for education, manpower and public knowledge and its utilization as shown in Figure 5. The contents

of this section summarize the overview. and the importance of research in four areas, namely the pillars of quantum technology in All 3 branches of Thailand and the application of quantum technology in another 1 branch in the next section. will mention placing

educational roots dissemination of knowledge to the public and engineering preparation (technical roadmap) and examples of research topics including a breakdown of budget estimates are included in Appendix A).

Summarizes the content and significance of each pillar of quantum technology.

3.1 *Quantum Computing and Simulation*

In many countries such as the United States, China, the United Kingdom, Singapore and the European Union. Calculation and simulation The quantum mechanics are separated into two branches of quantum technology with different roadmaps. Although the same physical system can be used, quantum computing and simulation have mechanisms. and different goals that is, arithmetic Quantum is also focused on building algorithms for fast computation and hardware to generate quantum. Computers use quantum principles such as superposition and entanglement, but quantum simulation is one quantum system to study another quantum system. which makes it possible to understand the system interested, more accurate, faster and more accurate The simulated system may perform a specific function. therefore cannot write Any program is the same as on a computer. But it is very useful because it can be used to study complex systems at the machine. Normal computers may not be able to work. or low efficiency Success in building a quantum machine Computing will be a milestone in quantum technology. which nowadays there is high competition in many leading co Google, Intel, IBM, Microsoft. With quantum computers, quantum communication is essential. and quantum metrology, but current research expects quantum computers to last at least another five years.

Thailand lags behind the rest of the world in quantum computing research. But Thailand should promote research in this field For example, build a small quantum computer. Maybe in the form of a quantum simulation that solve specific problems in the context of Thailand or software development and quantum algorithms for their own use in Thailand, Thailand should be prepared. Maybe in the form of research collaboration with foreign countries so that Thailand has Experts who can evaluate technology in this field.

3.2 Quantum Communication

Quantum communication is the use of quantum principles to communicate, process information, and protect the confidentiality of information. make communication highly secure Such communications include online transactions that rely on encryption and banking transactions. A key quantum principle that ensures highly secure communication is non-repetition. Or can copy the quantum state (no cloning theorem), making it safe from data theft In addition, quantum entanglement conditions will allow the transmission of information. Teleportation is more efficient. The quantum system that is critical to quantum communication is photons.

Quantum is a quantum random number generator. single photon production quantum key distribution protocols, quantum network construction requiring quantum repeaters, and satellite communications. Quantum communication is also linked to quantum computing. and quantum metrology because it is necessary to use light as an interface between quantum computers or between sensing devices.

For Thailand, there is very little research in this field. and lack of experts In the future, it is expected that each country It is necessary to have a certifying agent for quantum communication devices. Research in this field for the security of the country.

3.3 *Quantum Metrology and Sensing*

Quantum metrology and measurement is the application of quantum principles and properties to measurement. such as measuring time, measuring magnetic field intensity Medical diagnostics This quantum measurement, in theory, It will provide significantly more accuracy and precision. This makes it useful for technologies such as 5G and 6G communication technologies or the use of global navigation satellite networks.
Systems (GNSS), which rely on clock precision for processing and communications, metrology and geometries. Quantums are made possible by a variety of quantum mechanical systems, such as electron spins. The use of trapped atoms/ions, imperfections in NV centers in diamonds, quantum dot structures, and are expected to be the next technology. The quantum that was actually applied before the quantum machine. Computing and Quantum Communication

Thailand has several research groups doing research in this field and a number of researchers already exist. but still lacks systematic drive if seriously promoted It is expected that this field of quantum technology research can be developed into innovation. and works that can affect industrial development in Thailand

3.4 *Application Quantum Technology for National Development Prosperity of Thailand)*

Quantum technology will have a great impact on economic and social development. and everyday life, making quantum technologies empirically useful to the public. Not only creating knowledge in research is therefore one of the important goals of the quantum technology research network. The clarity of the application of quantum technology will be Identify each major area of relevant research. In summary, the application of quantum technology with high impact on develop Thailand and moving Thailand to have the ability to attract researchers and investors such as

• Material developments, such as high-efficiency energy storage materials. High Intensity Magnetic Materials for Generators electric or magnetic train This is linked to metrology and quantum measurement. Calculation and simulation Quantum mechanical both in terms of hardware and software.

• development of measuring tools and the process of increasing agricultural productivity through quantum knowledge, such as knowledge development or photonic tools for agriculture food, using principles, knowledge, or quantum tools to increase accuracy in agriculture (quantum-based for precision agriculture), the use of quantum tech for animal health, or the adaptation of energy-efficient fertilizer production processes. These applications are linked to metrology.

and quantum measurements and quantum computing

• Development of medical sensing, such as quantum sensing in cancer detection, which is linked to metrology and quantum sensing. DNA sequencing, which is linked to quantum computing • Secure communications and privacy amplification, including accurate clock generation. It is suitable for high-

resolution satellite-based (GNSS) network systems such as GPS and encryption satellites, as well as internet transactions that require high speed, accuracy and security, which are linked to metrology and geometries. quantum and quantum communication

• Development of quantum algorithms for banking and finance, such as stock market and investment risk analysis, borrower ratings and bad debt opportunities. which will rely on quantum computing •

Important logistics solutions for Thailand. whether traffic or water management which will rely on quantum computing and quantum metrology to measure geographic coordinates in detail.

• Optimization of detection of natural resources. and underground water sources or warning of changes geothermal, such as earthquake warnings which will be linked to the calculation and quantum metrology

• Development of chemical formulations for the production of drugs that respond to important diseases. Especially important tropical diseases for Thailand, which will be linked to quantum computing and simulation, both in hardware. and software search structure

research to develop new knowledge And research to apply quantum technology is therefore very important to develop Thailand Because it plays a role in many dimensions of economic and social development. and enhancing people's quality of life and national security

4. Building Foundation *The* development of

quantum technology in Thailand cannot be successful without the appropriate supporting factors. and efficient Major contributing factors include education, support from all sectors, both citizens and outreach, basic research and engineering. Pillars of the development of quantum technology And the supporting factor and its application can be clearly illustrated in Figure 5 for quantum technology research. Including research to apply quantum technology. Researchers in the network will be directly driven And linked to a roadmap for each pillar of quantum technology that requires a concise roadmap design, all of which are technical planning. So will be discussed in the next section.

In this section, contributing factors are systematically plotted to lay the foundation for the development of quantum technology. Thailand in a stable and sustainable manner. These factors include education and workforce building public releases and Attracting Research Funding and engineering that drives technological research Quantum

4.1 Education for Quantum Technology

Quantum technology is an advanced technology derived from deep knowledge in many fields. especially physics, mathematics, engineering computer science computational complexity or creating a tool Sensitive personnel need to be skilled. and highly skilled This may be a specific skill. or skills in many dimensions Systematic education management will help personnel Especially the young people in the country learn efficiently and quickly which It is one of the factors directly related to the country's competitiveness.

The basic educational structure related to quantum technology should be consistent with the three main research areas of the quantum technology development plan in Thailand. Education therefore needs to be carried out in harmony. to break down the research into smaller forms of teaching materials that are easy to understand convenient to broadcast This will result in students being able to develop as models in It can be commercialized and can be rolled back to enhance the potential of conducting primary research.

Education in quantum technology for Thailand is also exponentially important. Considering that the country following international research in this field And it is necessary to be prepared to support this technology. At the same time trying Position yourself to be able to develop your own technology. To drive industrial development in the quantum era and increase economic competitiveness with other countries Therefore, the quantum technology development plan in Thailand The goals and roadmap for the study of quantum technologies are outlined below.

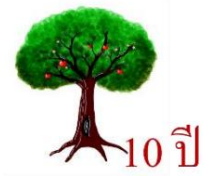
ÿ Undergraduate, Master's and Doctoral courses that promote skills suitable for technology.
Quantum

ÿ Activities or study topics for secondary school students.

ÿ Design training seminar content and micro credentials for
quantum technology

ÿ Adjusting content in the secondary curriculum to link with development.
quantum technology

ÿ Creating a graduate curriculum for researchers. and users of quantum technology



ÿ Create a career path for those involved in quantum technology.

ÿ Create organizations and activities for researcher development. and users continuously.
It is a study in the form of a multidisciplinary study. (multidisciplinary) or education
trans-disciplinary, consistent with innovation development and
drive industry

budget for education

plan	**Annual budget (million baht)**							
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7 - 10 **Total**	
Manpower budget	20.0	20.0	40.0	40.0	40.0	80.0	320.0	**560.0**
Operating budget	3.5	4.0	4.5	5.0	5.5	6.0	26.0	**54.5**

note

1. The first 6-year budget is derived from the sum of the budget expected to be spent on the basis of the projects specified in the roadmap.
2. The budget for the 7th – 10th year (if not proposed) will be calculated from the budget for the 4th – 6th year (average multiplied by 1.15-1.50)
3. For comparison Center for Quantum Technology Singapore (Center for Quantum Technology: CQT) takes the money. Approximately 15 million US dollars or approximately 450 million baht per year in the education manpower only (Annual Report 2013, Center for Quantum Technologies, National University of Singapore, p. 56). In 2013, the UK National Quantum Technology Program spent €50 million per five years for

Train and develop skills in quantum technology and spend 16.5 million euros per five years, or approximately 165 million baht per year for scholarships in quantum technology.

Main activities in human resource development is to produce Ph.D. (or the equivalent of 2 Master's students or 4 Bachelor's degrees) in each of the Quantum Technology Pillars. On average, each pillar produces 32 doctoral students or the equivalent per 3 years.

The main activities that require operating budget are (1) international conferences, (2) national conferences, and (3) educational network support structures. information technology, data warehousing and processing, including budget management, meetings, travel, documentation

4.2 Public Outreach

Development of a network of researchers, students and the general public who are both users And operators of quantum technology is of paramount importance. The dissemination of quantum technology knowledge is the key to developing and fostering its development. Quantum Technology in Thailand Thailand is a middle income country. and general public knowledge little quantum technology and there is a high level of misunderstanding In addition to strong research potential Researchers need to educate general public and induce participation in the use and properly support quantum technology Not misused or ignorant. In addition, researchers are extremely necessary to understand the problems of the industry both within the country and abroad in order to create. and transferring innovations that meet the needs of the country in the short and medium term. Including being able to create cooperation with the private sector This can lead to the development of both academic and industrial sectors together in a sustainable way.

ÿ Raising awareness and basic knowledge of quantum technology

ÿ Public and political motives

wills)

ÿ Build a research ecosystem for the research community and stakeholders.

ÿ Public investment promotion activities and the private sector in promoting and

develop research

ÿ 25% of the research budget from the private sector.

ÿ A link between the use of research results in industrial expansion and development.
country technology

ÿ 50% of the research budget from the private sector.

Public release budget

plan	Annual budget (million baht)							
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7 - 10 **Total**	
manpower budget	2.0	2.0	3.0	3.0	5.0	5.0	20.0	**40.0**
Operating budget	12.0	12.0	14.0	14.0	15.0	16.0	70.0	**153.0**

note

1. The first 6-year budget is derived from the sum of the budget expected to be spent on the basis of the projects specified in the roadmap.
2. The budget for the 7th – 10th year (if not proposed) will be calculated from the budget for the 4th – 6th year (average multiplied by 1.15-1.50)

Main activities for public dissemination of quantum technology is to raise awareness and educate Fundamentals of Quantum Technology as well as creating inspiration and showing career paths for the younger generation of Thailand In addition, the important function of the dissemination of quantum technology to the public is to create force Driven by the public and political wills, building a research ecosystem ecosystem) for the research community and stakeholders to promote joint investment between the public and private sectors in promoting and developing research and is a linkage to the use of research results to expand the results in the industry and develop the country's technology

4.3 Engineering work (Engineering)

Engineering is considered to be of great importance in research development. and bringing research into the production of workpieces Or create a suitable production process in the industry. Engineering is an important cog in the production of research. fast, efficient forming a solid technology base and can lead to sustainable industrial development Therefore, the main goal for engineering is a process-oriented joint research and tool making, and Ready process to develop quantum technology

because there will be quantum technology development in 3 main fields simultaneously in Thailand which these branches have maps own technical guidance but can share tools make engineering planning for

quantum technology including frontier research. Other fields must be concise and timely and

Usage according to the navigation map of each research area

goals and timeframes

ÿ Create necessary tools according to the navigation map of each branch.

ÿ Build a research ecosystem for quantum engineers. and those involved in Developing quantum technology

ÿ Design and build tools to further research in quantum technology as technology that can actually be used or as a production prototype (prototype)

ÿ Link and build processes to bring selected quantum technology prototypes to industrial production

budget for engineering

plan	Annual budget (million baht)							
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7 - 10	**Total**
manpower	20.0	20.0	15.0	10.0	10.0	10.0	46.0	**131.0**
Operating budget	10.0	10.0	10.0	10.0	10.0	10.0	46.0	**106.0**

note

1. The first 6-year budget is derived from the sum of the budget expected to be spent on the basis of the projects specified in the roadmap.
2. The budget for the 7th – 10th year (if not proposed) will be calculated from the budget for the 4th – 6th year (average multiplied by 1.15-1.50)

3. In the engineering department, the budget will be set up through the Project Management Unit (PMU) because it is a part of every department. Research projects take advantage And should not produce workpieces or buy redundant tools. Therefore, the budget in this section is not is included here

4. The budget in the table above is required by the engineering team. which has been evaluated into two parts: the value Raw materials and operating costs

Main activities of engineering Is to create a tool to support research in quantum technology, including bringing research results to create a prototype before entering into a commercial production process. However, if a team of engineers will do a research project, it The same can be requested for funding for other research projects.

5. Thailand Quantum Technology Roadmap & Milestones

This section summarizes the roadmap and key goals of quantum technology research in Thailand over the next 10 years, which are summarized into short-term (3-year), medium-term (6-year) and long-term (10-year) goals.) of research, development and application of quantum technology for Thailand. Each research topic has different production periods and uses different production resources. The content in this section is therefore only an overview. and estimated total budget for each research area. Specific details about the research topic, time frame, and expected outcomes are included in Appendix A.

1) Quantum Computing and Simulation in many countries such as the United States, China, the United Kingdom, Singapore and the European Union. Calculation and simulation The quantum mechanics are separated into two branches of quantum technology with different roadmaps. Although the same physical system can be used, quantum computing and simulation have different mechanisms and goals. that is, arithmetic Quantum focuses on building algorithms for faster computation and hardware to build quantum computers using it. quantum principles such as superposition and entanglement, but quantum simulation It is the use of a quantum system (simulator) to study another quantum system. The system used to simulate (simulator) will be less complicated. but can also simulate the core behavior of the system of interest. The system used to simulate may perform a specific function, so it cannot write any program like in a normal computer, but it is very useful because it Be able to study complex systems that normal computers may not be able to perform or perform with poor performance.

Success in building a quantum computer would be a milestone in quantum technology. which in this present High competition in many leading companies such as Google (Google), Intel (Intel), IBM (IBM), Microsoft (Microsoft), when there is a quantum computer, it is necessary to have quantum communication. and quantum metrology But current research is expected. that quantum computers will likely take at least another five years

Thailand lags behind the rest of the world in quantum computing research. But Thailand should promote research in this field For example, build a small quantum computer. Maybe in the form of a quantum simulation that solve specific problems in the context of Thailand or software development and quantum algorithms for their own use in Thailand, Thailand should be prepared. Maybe in the form of research collaboration with foreign countries so that Thailand has Experts who can evaluate technology in this field.

ÿBasic quantum computing and simulation systems

Demonstrate the benefits of quantum simulation.

Demonstrate the benefits of quantum computing with a signaled quantum system.

Medium disturbance (Noisy Intermediate Scale Quantum: NISQ) 50 qubits with long coherent time

ÿ Build original quantum algorithm clusters.

ÿProgrammable quantum computing and simulation system

Basic applications of quantum simulations such as cryptographic systems, audits, elections, lotteries, profit sharing insurance in cryptocurrencies. Rency (crypto-currency) A programmable logic qubit.

Original group of functional quantum algorithms

ÿ Quantum computation and simulation system that is superior to traditional computation.

Quantum simulations to solve problems in chemistry, materials science, and pharmaceutical science. Quantum algorithms used on quantum computers show the potential

Beyond the traditional calculation

Budget for Quantum Computing and Simulation

plan	Yearly budget (million baht)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7 - 10	**Total**
Manpower budget	240.0	240.0	240.0	320.0	320.0	320.0	1,472.0	**3,152.0**	
Operating budget	140.0	140.0	200.0	320.0	340.0	380.0	1,600.0	**3,120.0**	

note

1. The first 6-year budget is the sum of the budget expected to be spent on the basis of the projects specified in the roadmap. 2. The 7th-10th year budget (if not proposed) is calculated from the 4th year budget. – 6 (average multiplied by 1.15-1.50)

2) Quantum Communication Quantum

communication is the use of quantum principles to communicate, process information, and protect the confidentiality of information. make communication highly secure Such communications include online transactions that rely on encryption and banking transactions. A key quantum principle that ensures highly secure communication is non-repetition. Or can copy the quantum state (no cloning theorem), making it safe from data theft In addition, quantum entanglement conditions will allow the transmission of information. Teleportation is more efficient. The quantum system critical to quantum communication is photons. The main research area for quantum communication is quantum random number generation. Tam single photon production quantum key distribution protocols, quantum network construction requiring quantum repeaters, and satellite communications. Quantum communication is also linked to quantum computing. and quantum metrology because it is necessary to use light as an interface between quantum computers or between sensing devices.

For Thailand, there is very little research in this field. and lack of experts In the future, it is expected that each country It is necessary to have a quantum communication device certification body)certifying agent therefore it is necessary to promote (research in this field for national security

ÿ **Foundations for Quantum Communication**

Single photon source (SPS) and single photon detector

(single photon detector: SPD)

ÿbulk optics for demonstration of simple utilization, e.g.

Quantum random number generator (QRNG)

ÿ Quantum repeater

ÿ Highly efficient quantum communication

High performance single photon source and single photon meter

Transferring experiments from table top optical circuits (bulk optics) to in-house optical circuit experiments.

Optical waveguide circuit

ÿ Receiver and transmitter quantum key distribution (QKD)

Long distance, including ground stations for satellites to transmit quantum codes.

ÿ Quantum device interface unit

ÿ Quantum Internet

ÿ Quantum network system

ÿ QKD standards and certification organizations for transmitting quantum codes certification)

ÿ Quantum device interface

Budget for Quantum Communication (Quantum Internet)

plan	Annual budget (million baht)							
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7 - 10	**Total**
Manpower budget	40.0	10.0	10.0	50.0	10.0	10.0	400..0	**530.0**
Operating budget	90.0	30.0	20.0	170.0	50.0	40.0	100.0	**500.0**

note

1. The first 6-year budget is derived from the sum of the budget expected to be spent on the basis of the projects specified in the roadmap.
2. The budget for the 7th – 10th year (if not proposed) will be calculated from the budget for the 4th – 6th year (average multiplied by 1.15-1.50)

3) Quantum Metrology and Sensing

Quantum metrology and measurement is the application of quantum principles and properties to measurement. such as measuring time, measuring magnetic field intensity Medical diagnostics This quantum measurement, in theory, It will provide significantly more accuracy and precision. This makes it useful for technologies such as 5G and 6G communication technologies or the use of high-resolution satellite (GNSS) networks, which rely on the accuracy of Processing and communicating clocks, quantum metrology and measurement are made possible using a variety of quantum systems, such as electron spin. the use of trapped atoms/ions; complete in a diamond crystal (NV center in diamond), the arrangement of the quantum dot structure (quantum dot structure) and is expected to be a new generation of quantum technology that will be implemented before quantum machines. computer and communication

Quantum

Thailand has several research groups doing research in this area. and there are already a number of researchers but still lacks systematic drive if seriously promoted It is expected that this field of quantum technology research can be developed into innovation. and works that can affect industrial development in Thailand

ÿ International standard quantum metrology

Create devices and research that demonstrate the ability to measure quantum superior to traditional measurements

ÿ Apply the knowledge gained from quantum measurments.

To create academic acceptance in quantum measurement on the world stage

ÿ Prototype production of quantum sensors

Prototyping prototype quantum devices for telemetry standards Science and commercial sensor prototypes

Business incubation Including guidelines for creating a supply chain.

ÿ Quantum metrology to market and the world community

ÿ Real business benefits (commercialization) ÿ network of metrology systems and combined quantum sensors

Budget for Quantum Metrology and Measurement (Quantum Sensors for All)

plan	Annual budget (million baht)							
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7 - 10	**Total**
Manpower budget	160.0	110.0	45.0	40.0	20.0	20.0	130.0	**525.0**
Operating budget	282.0	200.0	149.0	120.0	64.0	64.0	268.0	**1,147.0**

note

1. The first 6-year budget is derived from the sum of the budget expected to be spent on the basis of the projects specified in the roadmap.
2. The budget for the 7th – 10th year (if not proposed) will be calculated from the budget for the 4th – 6th year (average multiplied by 1.15-1.50)

4) Application of Quantum Technology for Thailand Development

for Prosperity of Thailand)

The application of quantum technology is very necessary for economic and social development, and research drive Modern quantum technologies are useful in many dimensions as illustrated above (page 22). How useful quantum computing can be in solving logistical problems. Calculating the search for new materials or drugs available desired properties Or the benefits of quantum metrology in creating accurate, fast medical measurement equipment, etc. With the enormous benefits of quantum technology It is necessary to plan research and development (R & D) in an applied way, along with fundamental research, which is in line with the 4-step plan for technological development. Thailand's quantum is

Get ready to use quantum technology for real. knowledge building and creating some of their own technology

There is a high probability that applied research using quantum technology will yield good results. and manifested to the public before research to create the technology itself The success in the short period of this applied research will drive Mobile to strengthen research in quantum technology in Thailand. raise awareness of the importance of Technology is changing the coming world. and inspiration in education, planning and setting goals for Applying quantum technology is therefore important.

Since the applications of quantum technology are very diverse in each of the pillars of quantum technology, May not specify all topics to be applied, but planning and setting goals in key issues. will keep track of development Quantum technology is up-to-date, not obsolete, suitable for evaluating the strategies of future science.

ÿ Demonstrate the application of quantum technology

ÿ Build a research ecosystem for the research community users of quantum technology and those with involved

ÿ Devise integrated tools to create devices for specific applications ÿ Build organizations to promote the application of quantum technology in different sectors.

ÿ Expand research with clear application to develop new industries for Thailand

Budget for Quantum Deployment

plan	Yearly budget (million baht)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7 - 10	**Total**
Manpower budget	30.0	48.0	55.0	60.0	60.0	70.0		300.0	**623.0**
Operating budget	22.0	25.0	30.0	35.0	41.0	48.0		190.0	**391.0**

note

1. The first 6-year budget is the sum of the budget expected to be spent on the basis of the projects specified in the roadmap. 2. The 7th-10th year budget (if not proposed) is calculated from the 4th year budget. – 6 (average multiplied by 1.15-1.50)

Roadmap for the development of 3 fields of quantum technology and the application of next-generation quantum technology. of Thailand is in the same direction as the navigation map of many countries Especially the European Union from 2015 to 2035 (Figure 6), which started five years before the drafting of this quantum technology development plan of Thailand and has The period is longer than 10 years, but each planning phase has the same 10 year period.

due to the European Union And developed countries have relatively high capital to support research in new technologies and have a large number of researchers. (Compared to Thailand), therefore, all 4 pillars of quantum technology are invested in parallel and have continuous long-term planning. But what is noteworthy is that the directions of the research projects are particularly similar. especially in terms of quantum metrology and quantum communication Part of it is probably the result of technology. Quantum metrology has advanced knowledge to some extent. And the cost of doing research is not very high. (compared to Quantum computing) makes it easier for scientists around the world to create research. As for quantum communication, it is still not very advanced But only photon-based physical systems have outstanding properties. and can be used as the basis for Through quantum communication, the knowledge of the quantum physics properties of light has made great progress. make research directions in the field This is quite consistent. On the other hand, computational research and quantum simulations are much more diverse and complex. And it takes many elements to be successful, both capital and advanced engineering work. Controlling quantum mechanical systems to perform computational operations There are many different quantum systems. And each system has its advantages. different cons The research in this pillar is therefore not as clear as in the rest of the pillars. development of computational technology The quantum has advanced very rapidly. As can be seen from the list of calculations showing or high-performance processing than the traditional method is continuous Although Thailand has started research in this field late. But it's not too late to ha own

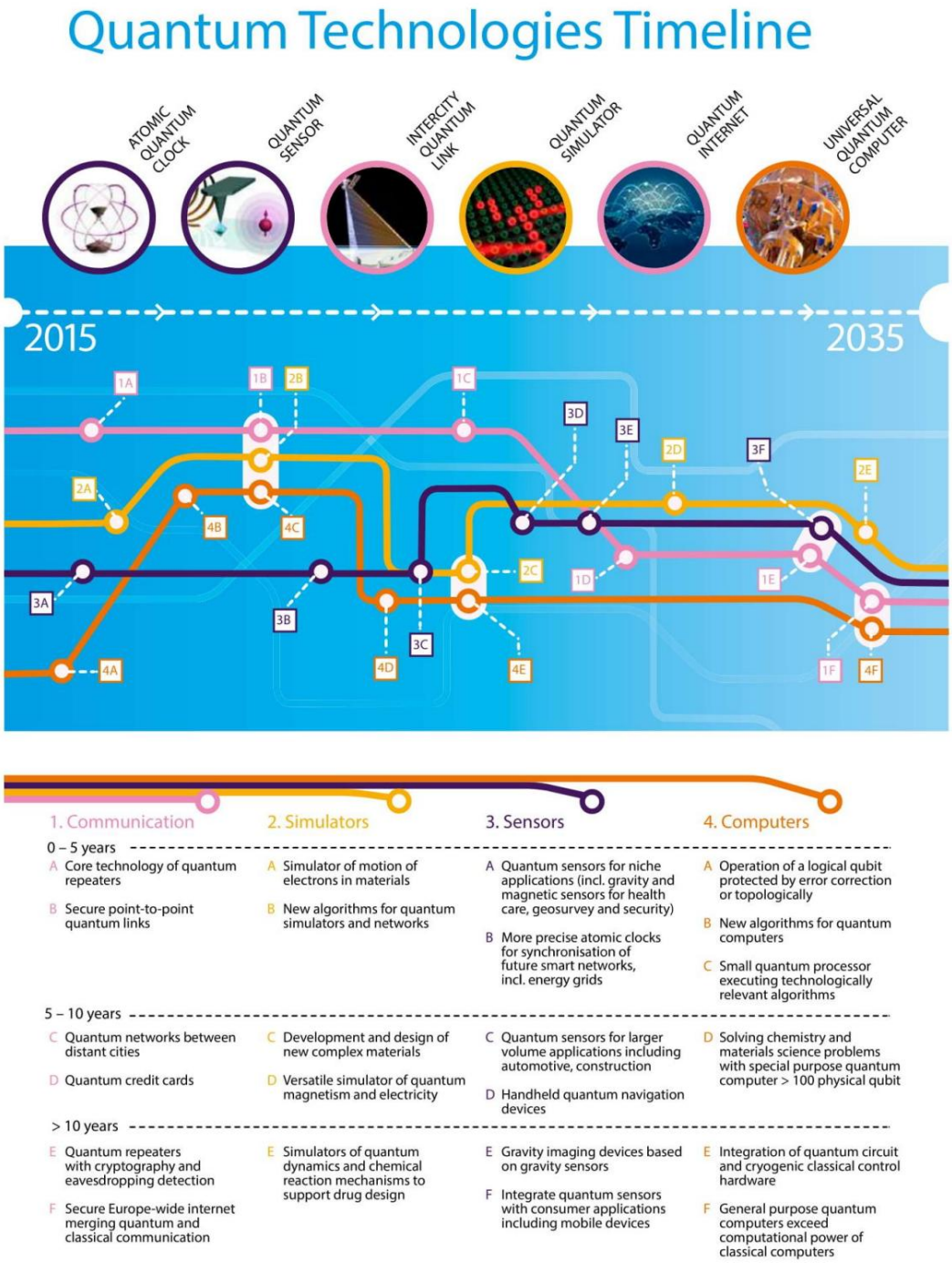


Figure 6 summarizes the EU quantum technology roadmap between 2015 and 2035.

Source https://gilkalai.wordpress.com/2017/04/03/the-race-to-quantum-technologies-and

quantum-computers-useful-links/

In summary, Thailand's quantum technology development plan has goals that are in line with the plans of the European Union. and many countries but has a narrower research framework less time and cost. By 2030, both Thailand and

The European Union aims to produce quantum sensors good enough for commercial use. science and application aims to create a quantum internet and aims to create a quantum machine computer that can be programmed (but the number of qbits in Thailand may be less)

6. Summary of Thailand's quantum technology development plan from 2020 to 2029

6.1 Summary of goals (milestones) of Thailand's quantum technology development plan

<table>
<tr><th>Education</th><th>Outreach/ Collaboration</th><th>Engineering</th><th>Highlighted Milestones</th><th>Applications</th></tr>
<tr><td>Selected topics/ activity to inspire young talent
✓New curriculum for B.Sc., M.Sc & Ph.D. in Q. tech.</td><td rowspan="2">✓ 10 International Collaboration (China, EU, US, UK, Canada, Australia, Japan, Germany, Singapore, Korea)</td><td rowspan="2">✓Essential tools for Q. tech research
• in-house engineering
• precision control & automation</td><td>✓50 qubits fault-tolerant quantum computer
✓ Quantum AI/ quantum machine learning</td><td rowspan="2">✓ Quantum-assist algorithms applications in finance, genomics, pharmaceuticals, logistics, metrology, etc</td></tr>
<tr><td>Micro credentials/ training modules/ researcher reskills</td><td>✓ Q. Tech Career Path Training Program</td><td>✓Necessary fab. lab./infrastructure</td><td rowspan="2">✓ Quantum Internet
• QRNG
• optical circuit on chips
• quantum interface
• global navigation satellite systems/satellite Q</td><td rowspan="2">✓ Quantum Materials/ Quantum Chemistry
✓ National security
✓ Fast and secured transactions/transmission</td></tr>
<tr><td>International workshops/ conferences</td><td>Ecosystems for quantum tech./ new industry</td><td>✓Prototypes for industrial use</td></tr>
<tr><td rowspan="2">✓Critical-mass Man Power Development
• 114 Doctoral Researchers
• 456 M.Sc. Technicians
• 1824 Users</td><td>✓ Funding (50%) from Private Sector</td><td>✓R & D on Quantum Devices</td><td>✓ Internationally verifiable unit standards</td><td>✓ National visibility/ international acceptance</td></tr>
<tr><td>Raise public awareness, public and political wills to prepare Thai society transition to quantum technology era</td><td>Transition assistance for commercializing products to investors/industry for large scale manufactoring</td><td>✓Commercializable quantum sensors for all
• Portable gravimeter
• Compact atomic clock
• Magnetometer
• Photonics biosensors
• Kibble balance</td><td>✓ Quantum sensors usage
• Q. sensors in agriculture/ food technology
• Q. sensors in medical diagnostics
• Q. sensors in natural resources detection</td></tr>
<tr><td colspan="3">Building Foundation</td><td>Deliverables</td><td>National Benefits</td></tr>
</table>

Figure 7 summarizes the goals and key research topics for the development of quantum technology in Thailand during 2020-2029. Details of the goals, guide maps, and budget estimates for each topic have been compiled. in Appendix A

6.2 Budget summary for 10 years

Table showing budget for the first 6 years

plan		Annual budget (million baht)							continuation branch (million baht)
		Year 1	Year 2	Year 3	Year 4	Year 5	year 6	together	
Quantum Computing	manpower budget	240.0	240.0	240	320.0	320.0	320.0	1,680.0	3,200.0
	Operating budget	140.0	140.0	200	320.0	340.0	380.0	1,520.0	
Quantum Communication	manpower budget	40.0	10.0	10.0	50.0	10.0	10.0	130.0	530.0
	operating budget	90.0	30.0	20.0	170.0	50.0	40.0	400.0	
Quantum Metrology & Sensing	manpower budget	160.0	110.0	45.0	40.0	20.0	20.0	395.0	895.0
	Operating budget	130.0	100.0	110.0	80.0	40.0	40.0	500.0	
Education	manpower budget	20.0	20.0	40.0	40.0	40.0	80.0	240.0	265.0
	operating budget	3.5	3.5	4.5	4.0	4.0	5.5	25.0	
Outreach	manpower budget	2.0	2.0	3.0	3.0	5.0	5.0	20.0	103.0
	operating budget	12.0	12.0	14.0	14.0	15.0	16.0	83.0	
Engineering	manpower budget	20.0	20.0	15.0	10.0	10.0	10.0	85.0	145.0
	operating budget	10.0	10.0	10.0	10.0	10.0	10.0	60.0	
Application	manpower budget	30.0	48.0	55.0	60.0	60.0	70.0	323.0	524.0
	operating budget	22.0	25.0	30.0	35.0	41.0	48.0	201.0	
Annual budget (million baht)		919.5	770.5	796.5	1,156.0	965.0	1,054.5	5,662.0	

Table showing budget by period (3 years or 6 years or 10 years)

plan		Annual budget (million baht)				total per branch (million baht)
		Year 1-3	Year 4-6	Year 7-10	together	
Quantum Computing	manpower budget	720.0	960.0	1,472.0	3,152.0	6,272.0
	Operating budget	480.0	1,040.0	1,600.0	3,120.0	
Quantum Communication	Infrastructure 60.0		70.0	130.0	260.0	1,260.0
	operating budget,	140.0	260.0	600	1000.0	
Quantum Metrology & Sensing	manpower budget	315.0	80.0	130.0	525.0	1,293.0
	Operating budget	340.0	160.0	268.0	768.0	
Education	manpower	80.0	160.0	245.0	485.0	531.0
	operating budget	11.5	13.5	21.0	46.0	
Outreach	Infrastructure	7.0	13.0	20.0	40.0	193.0
	operating budget	38.0	45.0	70.0	153.0	
Engineering	Infrastructure 55.0		30.0	46.0	131.0	237.0
	operating budget	30.0	30.0	46.0	106.0	
Application	Infrastructure 133.0		190.0	300.0	623.0	1014.0
	operating budget	77.0	124.0	190.0	391.0	
Total budget each year (million baht)		2,486.5	3,175.5	5,138.0	10,800.0	

6.3 Links to other Frontier Research in Thailand

Thailand has a plan to develop leading-edge research in 3 main fields:

(1) Physical Science Frontier Research, consisting of High Energy Physics, Space, and Quantum.
Technology

(2) Biological Science Frontier Research consisting of Health and Food.

(3) Social and Humanity Frontier Research

Each field of front-line research develops its own road map. Quantum technology development plan of Thailand (Thailand Quantum Technology Roadmap) can show the relationship of research in Quantum technology and other fields are shown in Figure 8.

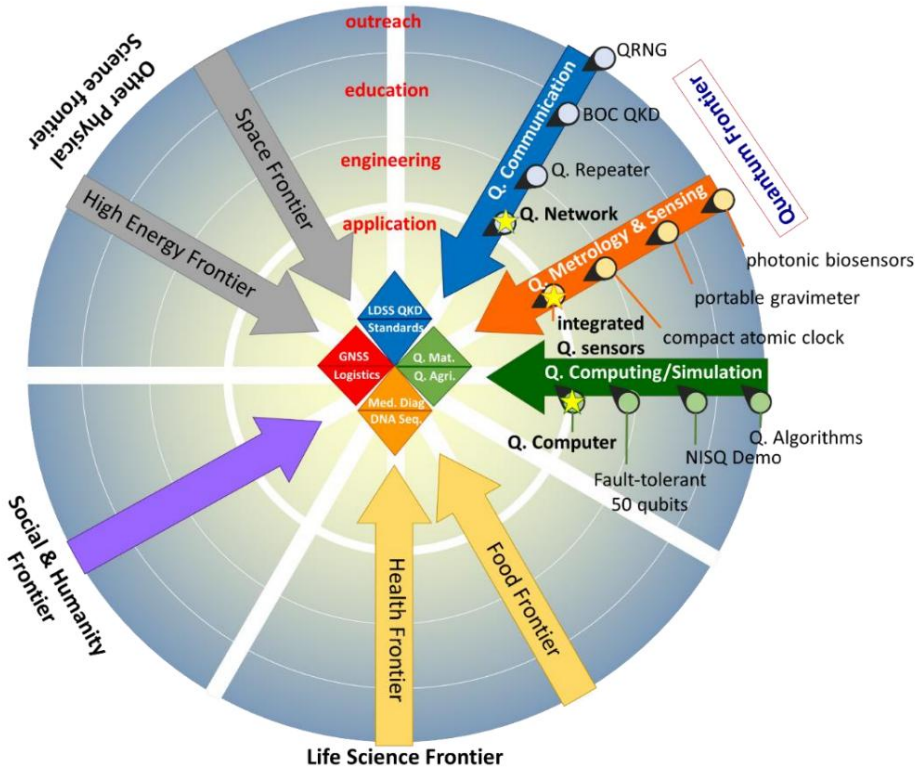


Figure 8 The connection of quantum technology to other fields of advanced research in Thailand.

Note: The meaning of the abbreviations in Figure 8 (definition and description in Appendix B).

Q. App = application quantum technology QKD = quantum key distribution

Q. Repeater = quantum repeater BOC = bulk optics circuit

Q. Mat. = quantum materials GNSS = global navigation satellite system

DNA seq. = DNA sequencing Med. Diag. = medical diagnostics

LDSS QKD = long distance super secure quantum key distribution

Appendix A details each pillar of quantum technology.

1. Quantum Computing and Simulation communication equipment or

computer As a result of the application The basic knowledge of science discovered in the early 20th century, quantum principles, was developed. It was the transistor in 1947. These technological developments were driven by the global economy and the need for technology to meet the growing population of the world. And the rapid increase in information has resulted in new technologies that are more efficient than ever every year, as can be seen from the number of transistors in The computer cycle doubles every 2 years (Figure 9).

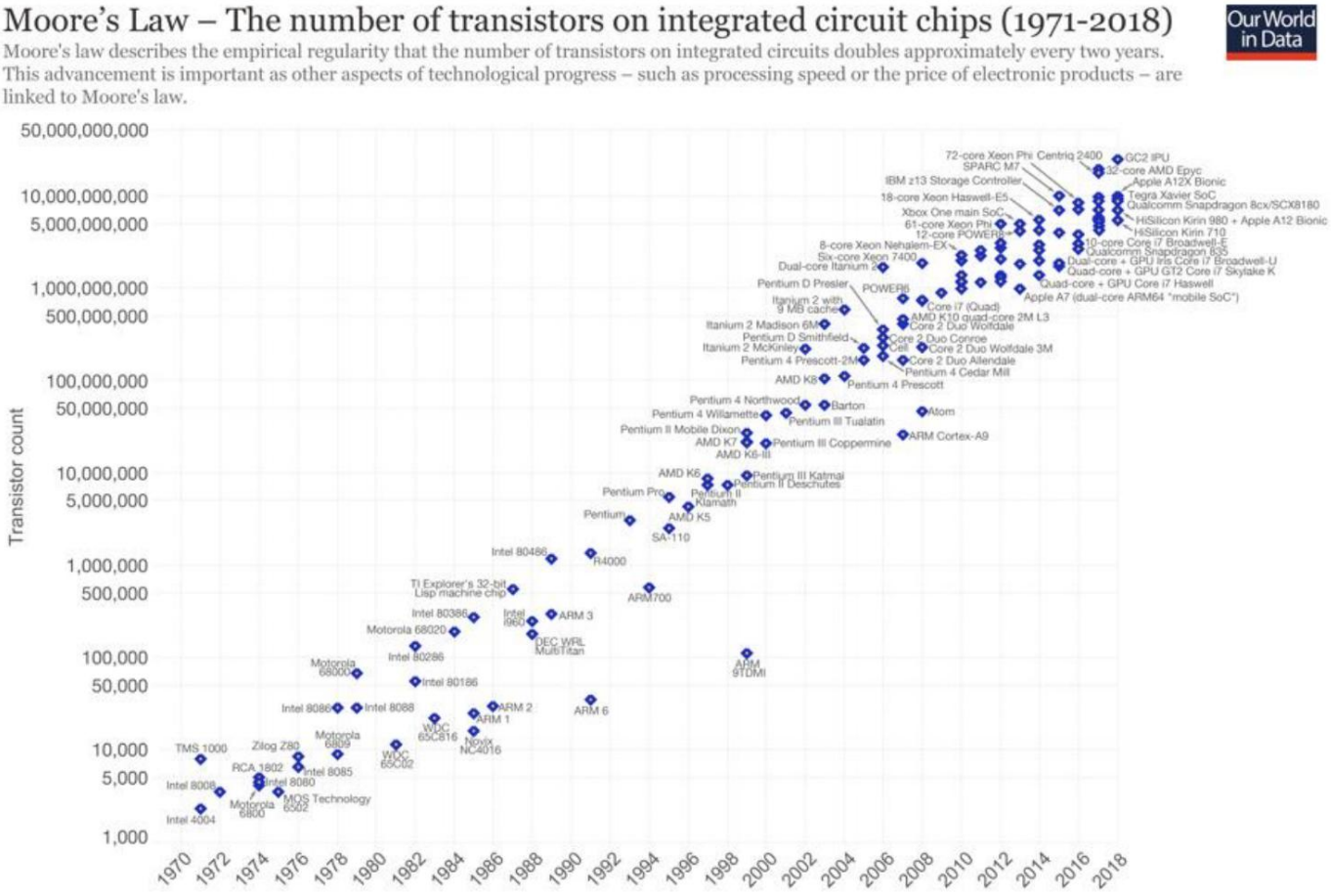


Figure 9. Moore's law predicts that the number of mysisters doubles every two years. Image from https://ourworldindata.org/technological-progress.

from the need to process faster, more precisely and more utilitarianly cause the necessity will build a processor (more microprocessors) in a limited space This reduces the size of the microchip to just a few atoms. This makes its behavior different from the properties of normal matter. and show more quantum properties. Quantum principles therefore inevitably play a role in the development of technology. As they get smaller to the atomic scale, greater control over individual atoms is required. In the near future (within 10 years), these technologies will meet their limits as developments take place. The potential of computers in use today. The fundamental limit is reached because the behavior of individual atoms may be difficult to control. which will result in slowing down economy and limit social development

Quantum computing and simulation is the application of quantum theory as a basis for creating new computational methods or algorithms that are more efficient than conventional computational methods. Used in general computers today, quantum computing will be useful in the development of many other related sciences and technologies, such as the study and design of the chemical structure of medicines, chemical fertilizers, or new materials, or the development of artificial intelligence (Artificial Intelligence: AI) to be more efficient, etc. This new type of calculation may be a form of calculation. True quantum (quantum algorithm), which requires a quantum computer (quantum computer) or a quantum simulator (quantum simulator) in processing. or it may be a new computational model that relies on quantum principles but can also be processed using a normal computer The latter is known as the resulting algorithm. inspired by quantum (quantum-inspired algorithm) for clarity and classify arithmetic calculations Quantum vs Quantum Simulation We can summarize the definitions of both as follows.

Quantum computing: The study and development of computing

technology based on Principles and theories of quantum mechanics are the coherent superposition state and entanglement, squeezed state and decoherence. (decoherence) or error of quantum information **Quantum simulation:** a problem-specific process for studying quantum systems. That is difficult to do in a lab and cannot be simulated using a supercomputer.

because it focuses on observing the kinetics

of the quantum system Quantum simulations therefore do not require the error correction process of quantum bits. (quantum bit or qubit) in

current computing and quantum simulation technologies. Both in terms of hardware and software are things. where many countries, including many private companies, are actively interested in R&D. with faith that the success in developing this technology will result in another industrial revolution, so those who have access to and Understanding this technology will be able to gain advantage in terms of science and economy. for Thailand development The hardware side will not be able to get into the forefront of the world. because it requires a very high budget But the readiness and

able to use quantum computing technology will be able to do so without losing business opportunities And increase competitiveness. The application of quantum computing will help improve the quality of life of the population. direction of research and development Appropriate quantum computing and simulation technologies for Thailand may be divided into 4 main topics:

(1) Quantum Computer Hardware and Quantum Blind Computing

(2) Quantum Simulator

(3) Platform-independent Quantum Algorithm and Quantum-inspired Algorithm

(4) Potential Problem Seeking and Quantum Solution

finding interesting and useful problems and using existing algorithms to demonstrate solving those problems will show see the potential of quantum computing technology Specific problems in the Thai context should be emphasized in order to Society is becoming more aware of the benefits and opportunities that come with new technology. The direction of development in each topic is as follows.

(1) Quantum Computer Hardware and Quantum Blind Computing

With limitations in manpower and fundamental economic and technological factors. Research investment in hardware that quantum computing Thailand should not compete in the same technology as big companies like Google. (Google) or IBM (IBM). A more interesting alternative is to use foreign open quantum computers. It is available through a cloud service, which requires the necessary funding to access the available system. The number and efficiency of qubits are sufficient to be used in this dimension. Serious research on 1) the development of a small quantum computer with our own technology Including support system 2) quantum blind computing, a system that protects information that is sent to be calculated through the cloud system to be safe cannot be accessed either by quantum operators computers and other bad actors in the network (network). The development of research in this way must be done carefully. It is also in line with research developments in the field of quantum communication.

(2) Quantum Simulator

Thailand should also develop hardware for quantum technology, but the first 10 years should be hardware development for quantum simulations. which has a high probability of success and should be Supported because the process of developing such a system is less complex than building a quantum. very computer In addition, many domestic research groups have the potential to develop quantum simulation systems on their own. (Even if the number of qubits is not large) could make an international contribution to the study of qubit tolerance control.

control), decoherence suppression, or to study the disturbance of the system (noise spectroscopy). These knowledge are still at the forefront of research. and is in great demand Improved programmable quantum computers (programmable quantum computer), moreover, if Thailand can build quantum simulation hardware It will be highly useful to use. Solve problems specific to the Thai context without having to pay for foreigners. and may be the service provider itself

Since there are many physical platforms that can be developed as a simulation system. Quantum physics, such as linear optics or trapped neutral atoms or trapped ions, or the spin of electrons or nuclei. (electron/nuclear spins) or diamond imperfections (NV-center diamond). Each system has advantages that can be brought. can be complemented together to become a highly efficient simulation system Support in this area should therefore be available to all systems, in line with the European Union's quantum simulation hardware roadmap.

The development of short to medium-term quantum simulations should focus on signaled quantum systems. Medium interference (Noisy Intermediate Scale Quantum: NISQ), which is a quantum system that still has a number. There are not many qubits and there is no efficient decoherence management process. Because this type of system is Systems that can be built faster and capable of solving certain problems better than machines. Normal computers can be used. In this respect, Thailand needs to create the readiness of personnel both as researchers. engineer and user So that it can help build the hardware of each system. The development of such personnel may be Conducting through specific

training (workshop) and in educational courses which must be harmoniously linked with work, education and outreach in software and algorithm research related to quantum simulators (quantum simulator) can be divided into 4 parts: (1) algorithms and software (algorithm and software for hardware interface) (2) noise management software using artificial intelligence to help resolve di (AI-assisted quantum error correction), (3) quantum advantage certification software, and (4) quantum simulation algorithms. simulation algorithm), which requires cooperation with the development of quantum algorithms in the long term. The ultimate goal of

the 10-year quantum simulator development should be the ability Making chemistry and quantum materials (quantum chemistry/materials) more efficient, including solving for research medicines, other important problems in Thailand such as on special properties, fertilizers or new logistics problems, including traffic and water management etc.

(3) Platform-independent Quantum Algorithm and Quantum-inspired Algorithm

This part of the research is to develop algorithms related to computational processes to solve various problems, both quantum algorithms and algorithms inspired by quantum principles. It is a quantum-inspired algorithm that is independent of the physical system, so research in this field can be done immediately independent of the develop hardware However, the long-term research direction must focus on the adoption of algorithms and software. Many of these come to test. and used with developed hardware The

development of high-level algorithms in the early stages should concentrate on both quantum-algorithms and quantum-inspired algorithms. together, with an emphasis on An algorithm inspired by quantum principles is more than the first. Because of this type of algorithm Can be used in normal computers immediately. and gradually promote more quantum algorithms in a phase

medium to long term

(4) Potential Problem Seeking and Quantum Solution

It is important to find suitable problems and how to solve them using quantum technology, because it shows the potential of quantum technology. At the moment, the problem that researchers have used to demonstrate such potential It's often an unrealistic problem in real life. But it clearly shows the development of quantum technology. Every country has its own problems that fit their context. Thailand has its own context-specific problems that may be addressed. Considering and trying to solve the problem for a long time and may not be successful. The development of quantum technology in Thailand, especially in the field of quantum computing, is a possible hope. Make these problems solved. or at least enhance the computational process that makes the ability to solve problems more efficiently or improve the situation.

A suitable problem for Thailand needs to be seriously studied. and do it in conjunction with Readiness and potential of quantum technology that Thailand has access to These problems may include increasing agricultural productivity, solving logistical problems such as traffic, or managing water. Finding a reduction in the time for the synthesis of drugs that suitable for tropical diseases and finding suitable materials These problems will be discussed in detail in the section Application topics of

quantum technology Another important issue that needs to be considered in quantum computing. is a connection (interface) between hardware and software In this respect, Thailand has to consider whether to create this technology on its own or to choose from existing technology in the market.

Benefits of Quantum Computing and Quantum Simulation

New designs to keep pace with pathogen mutation rates Seeing and studying cancer at the atomic level, designing and synthesizing non-natural proteins modifying the structure of human cells to prolong Longevity or non-disease cause Material design with specific properties or utility for use. on Earth and the harsh conditions in space. Fast calculations will make more profit in a shorter time which will decide the player. win in the stock market The ability to deal with big data so quickly that it will cause the collapse of Traditional economics that relies on predictive market models. These game-changing effects and more at Current technology is not able to provide The main reason is that the power of the calculator is not enough to make the data and Knowledge is further developed into understanding and eventual use. The fastest supercomputer today

(Oct. 1, 2019) is the Summit – IBM Power System AC922 with 2.28 million compute units. It can calculate 1.87 x 1017 cycles per second and consumes 8.81 million watts of power, which is the same amount of power that lights Pattaya up. The system consists of 50 subunits (here, 50 atoms) only. To deal with a 51-atom system, we need 2 Summit – IBM. according to) of the quantum system. For example, when the number of atoms N = 60, the energy used for supercomputers will be able to drive an electric bulb to light up Thailand (which the value of building a Exponential Resource Demand (2^N supercomputer of this scale is beyond imagination) and when N = 300, the **amount** of bit data will be greater. The total number of atoms in the universe that astronomers can see. The shocking thing is In its complex nature, the number 300 is not even close to the number of atoms in one mole of solids that can be dropped on the tip of a pinky finger. and there is no way For which we will calculate human genomic DNA (gDNA), which is composed of approximately atoms. 204,000,000,000 atoms. The only answer humans have to surpass the boundary of 60 atoms, or 60 subunits, is quantum computers and quantum simulators. Because upgrading a 50 qubit quantum calculator (bit quantum) to 300 qubits only requires an additional 250 atoms in the computation system.

1.1 **Milestones & Roadmap Milestones & Roadmaps** Milestones for

Quantum Computing and quantum simulation is to have both hardware and software Working together to promote each other The overall metrics are three key factors: qubit count, connectivity, and noise. Abbreviations used in target identification are as follows.

QSim stands for Quantum Simulation System. Overall, the goal is to increase development capabilities.

NISQ Refers to a quantum system with medium noise. In general, the goal is to find the extent to which Quantum computers are better than today's computers. and find new ways to use qubits

QCom stands for Quantum Computing. which aims to increase the quality of the qubits by creating construction, characterization, validation and verification, abbreviated as qCVV.

QSoft means Quantum Software. which aims to develop applications with quantum computers that will built up

goals and timeframes

duration goal		**Impact/challenge/confidence**
3 years	• (QSim) Quantum simulators with quantum advantage on the scale of 500 lattices. • (NISQ) Noisey intermediate-scale quantum (NISQ) computing demonstrates quantum advantages. • (QCom) Fault tolerant for few qubits proven with plausible routes toward 50 qubits. • (QSoft) Quantum-inspired algorithm • (QSoft) Quantum machine learning • (QSoft) ML-assisted quantum error correction	3/4/5 3/4/5 5/5/4 3/4/5 3/4/5 5/4/4 4.2
6 years	• (QSim) Quantum optimization and quantum advantage in solving important problems in science. • (NISQ) Noisy intermediate scale quantum system • (QCom) Robust logical qubits realized to make quantum processor (programmable). • (QSoft) Quantum blind computation (connect with quantum communication)	4/5/5 4/5/5 5/5/5 4/5/5 4.75
10 years	• (QSim) Quantum optimization and quantum advantage in problems beyond supercomputer capability, eg quantum chemistry, novel materials and drug designs. • (NIQS) • (QCom) • (QSoft) Quantum Chemistry/Materials	5/5/5 5/5/5 5/5/5 5/5/5 5.0

navigation map

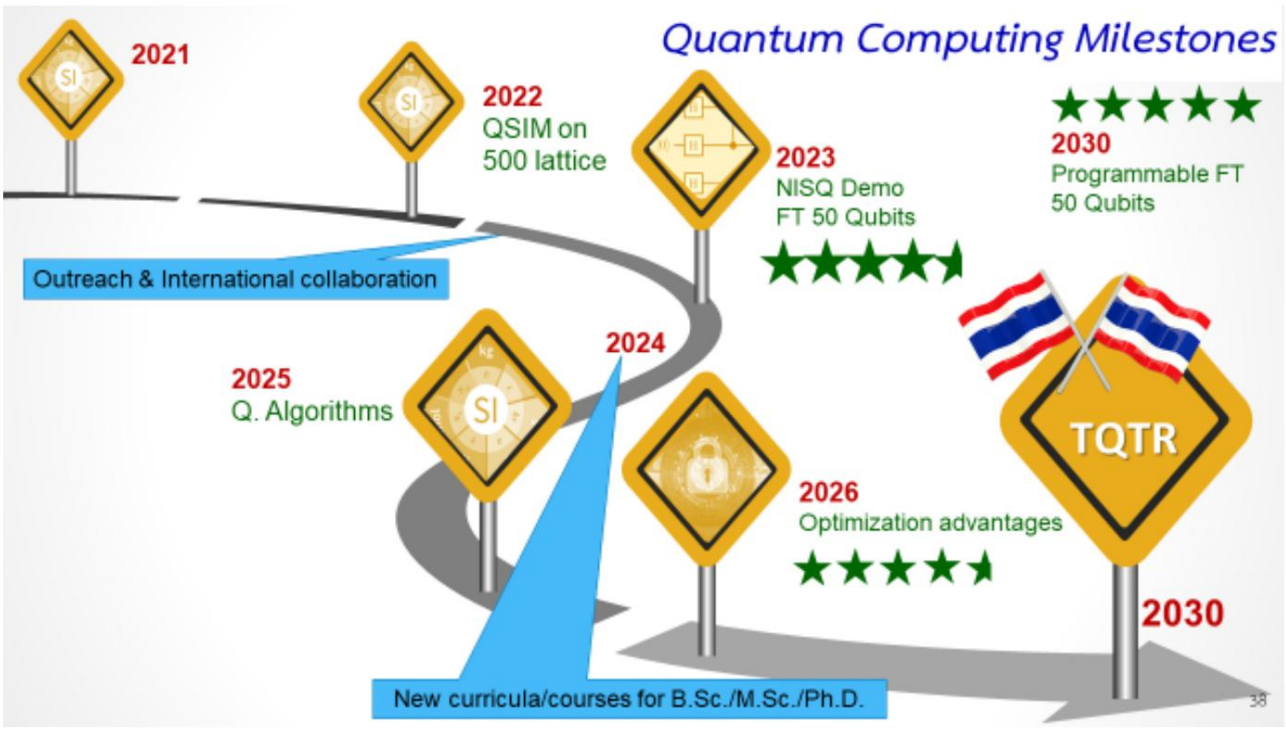


Figure 10. Goals and road map of quantum computing.

1.2 **Application Goals** o 3-year period

Solve small logistics and other fundamental problems with a quantum computer.

o 6 years

Solve problems in the context of Thailand, such as agriculture and natural resource acquisition

o 10-year period

Using quantum computers to solve specific problems such as chemistry, artificial intelligence internationally, compete with international

1.3 **Necessary supporting factors (Enabling Tools)**

1) technology to construct qubit, superconducting qubit, ion-trapped qubit and other candidates

2) computing facilities for large scale simulation to develop QSim

3) access to existing Quantum computers to develop software and testing the algorithm

1.4 **Budget** _

1.4.1 Infrastructure (million baht)

target	Year 1 - 3	Year 4 - 6
facility to construct superconducting qubits	120.0	180.0
facility to construct neutral atom and ion-trapped qubit	120.0	180.0
equipment and materials to assemble superconducting qubits	240.0	300.0
equipment and materials to assemble qubits into a system	240.0	300.0
total	**720.0**	**960.0**

1.4.2 Operating budget (million baht)

target	Year 1 - 3	Year 4 - 6
construct superconducting qubits	60.0	120.0
construct neutral atom qubit	60.0	120.0
construct ion-trapped qubits	60.0	120.0
testing other technology for qubits	48.0	48.0
assemble superconducting qubit into a system	48.0	120.0
assemble neutal atom qubit into a system	48.0	120.0
assemble ion-trapped qubit into a system	48.0	120.0
demonstrate computing on qubits	36.0	90.0
develop system software	30.0	72.0
develop application software	30.0	72.0
develop algorithms	12.0	38.0
total	**480.0**	**1,040.0**

2. Quantum communication

Quantum technology can bring great benefits to communication systems. Conventional communication using electrical signals and data processing or data encoding systems by applying the nature and engineering of electromagnetic field theory.

The old scheme will be replaced, reinforced by quantum theory and information control. which will have different natural behavior Such quantum behavior such as no-cloning, superposition, and

Entanglement, which is the foundation for more secure communications. and with communication

It is necessary to transfer information between points, quantum encoding it in the state of photons. (The quantum particle of

light), which has a very high speed of movement and a good feature is that the information cannot be disturbed to change from The environment is easily assessed as the most suitable option. Data in

communication systems is generally protected by encryption. (cryptography) to prevent data theft. The security of a communications system is assessed by how easy it is for an attacker to decrypt it. In general, the system Quantum cryptography has less technological limitations than quantum computers and quantum simulations. Because it relies on a smaller number of qubits, only at least 2 qubits can be operated. Challenges of quantum cryptography development It is a long-distance high-security data transmission that is expected to be built and deployed in more than 10 years from now.

Encryption systems can be broadly divided into two types: asymmetric encryption (ASE) or public-key encryption. cryptography), where the receiver and the sender use different codes. and symmetric encryption (SE), in which the receiver and sender use the same password. By asymmetric encryption as Important elements in today's internet system It is evident that ASE systems can be hacked at all if they use high-performance quantum computers. But it is one of the advantages that the machine

Such quantum computers have yet to be developed due to technological limitations. pattern coding Symmetry has less technological constraints and is believed to be able to be built and implemented within a 10-year time frame. Symmetric cryptography will be developed in five key subsections (5Q), namely:

(1) Sources and key readers for encrypting transmitted data over long distances (2)
Quantum repeaters (QR) for repeating and amplifying signals for
send data remotely
(3) Quantum random number generators (QRNG) devices to generate random numbers for one-time password (OTP)
(4) Quantum information masking devices (quantum steganography (QS)
and blind quantum computing (BQC) to create an alternative system to protect information on the sender side; (light-
matter interface: LMI) that links the system The photon quantum with other quantum mechanical
systems such as NV-center in diamonds, semiconductor qubits. They are used in semiconductor qubits, trapped ions and
fiber-based memory because of their good properties as light. The medium of message information, but cannot be
stored in memory, therefore requires the interaction between light and qubit or other quantum systems. or these
parts come together as a communication network system, which can

can be considered in 3 levels of development

(1) Laboratory level development The equipment will still be large and able to perform high-security communications. in the near term

(2) Smaller device development and high-security communication over a short distance (3) High-security communication over a long distance both in the system through free space cables and satellite systems

2.1 ***Milestones &*** **Roadmaps**

duration	goal	Impact/challenge/confidence
3 years	**In the early stages, building elements (5Q) of Quantum will be the first step. This requires research and development of devices in the following areas :** • Double or more photons with entangle single photon source (ESPS) as transmitters and single photon detection (SPD) systems.) as a receiver • Optical circuit for data processing at experimental scale (bulk optical circuit: BOC) • Quantum Random Number Generator (QRNG) at laboratory level or field testing, including related intellectual property. • Single-photon quantum repeater (QR) • Laboratory-scale QS or BQC • Development of integrated optical circuits for applications with polarized light. (polarized light) • Build and test the LMI system.	4/5/4 4/2/5 5/3/5 5/5/3 5/5/3 5/5/3 5/5/3 (average 4.2)
6 years	The medium-term goal is to integrate devices from 5Q into a test **bed- level quantum communication system as a fundamental process. potential development and Operational availability of each device Species must also be developed in parallel.**	5/5/3

duration goal		Impact/challenge/confidence
	• Testbed bulk optic QKD system) from the 5Q device	5/5/3
	• OC on waveguide (OWC) systems in terms of coupling, fabrication, loss-free, functionally identical optical properties. BOC-based devices such as *polarizers,* wave plates, polarization beam splitters, lenses	5/5/3
	• Higher efficiency SPS provides an entanglement state with high fidelity and can entangle a number. larger qubits for the benefit of universal error correction, qubit processing coupled with miniaturization technology. to be able to create in the OWC system	5/5/3
	• Higher quality SPD with scalability. can be embedded in the OWC system, can be combined with the SPS, must be developed make bitrate higher	5/5/3
	• QRNG generation on OWC system has higher bitrate.	5/5/3
	• QR in the OWC system and has the ability to increase the distance communicate higher	5/5/2
	• Development of receiver-transmitter as ground station and payload for satellite communications which must cooperate with the agency abroad in terms of satellites and payload systems	5/5/3
	• Quantum communication system both using OWC and in cable. There is a study on the possibility of leakage / theft of information. In practice, along with protection and correction (privacy amplification) • QKD Certification •	5/5/4 (average 4.3)
10 years	Quantum Communication System and the quantum network (quantum network) where the data transmission system is developed on OWC or BOC for communication systems in free space or satellite systems • Commercialized repeater/QKD	5/5/2 5/5/2 (average 4.2)

navigation map

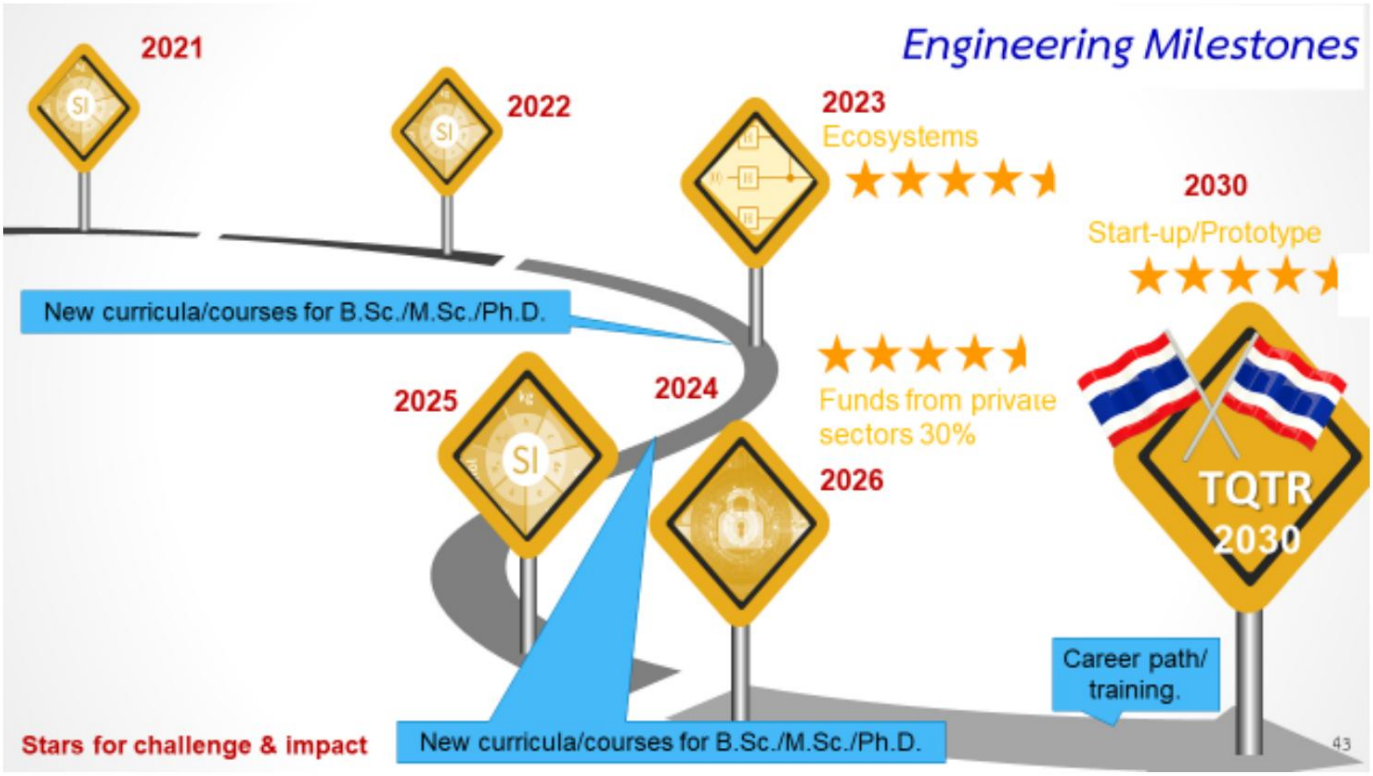


Figure 11. Goals and road map of quantum communication.

2.2 **Application *Goals*** o 3-year period

Because in the beginning it is still the basic equipment for the integrated system. the direct benefit of Communication is therefore not born until these devices have been

developed to be complete above. However, since the development of these devices is based on the principles of quantum information, indirectly the development of quantum information devices using light can be the basis for the development of quantum technologies. Other fields include metrology and measurement, quantum computing, quantum computing. and quantum simulation Both in direct light-based qubits and as a key component of optical technology in all quantum information technologies, it can also be developed into industrial applications that rely on optical processes such as electronics. to have a higher capacity

o 6 years

Because the medium term divides the implementation of two approaches. The first approach is to develop various devices to have higher potential This will directly benefit the quantum communication system in the next phase and also develop the capability The ability of optical technology to support the utilization of quantum technology research.

together and in the next industry

Another approach is to build an optical device on top of the OWC system, which will improve the device's performance. Smaller and higher quality because they are more difficult to be disturbed. can be extended to the development of medical devices Optics as in the first 3 years, but with higher quality and accuracy. and because at the end of

The six-year goal is to build a full-fledged cable-based quantum communication system. therefore will be used in

Communications that require high security that can be done through wires such as No communication between departments. Restrictions on wiring It will be aimed at financial institutions. and security agencies

o 10 years

The goal of the last phase will be to build a high security communications network system using the system. Quantum, which is aimed at long-term use in communication systems at all levels including households, departments and agencies. It relies on highly secure communications such as Security agencies and financial institutions

2.3 **Necessary supporting factors *(Enabling Tools)***

1) Silicon waveguide unit and ring resonator fabrication

2) semiconductors or alternative systems to create light-sources and photons detectors embedded in waveguide system

3) Satellite Communication Support System Have infrastructure for ground station development and have Cooperate for the use of payload systems on satellites (developed by research cooperation with foreign countries such as China or Canada)

2.4 Estimated budget

phase / **time**	**research activities**	**Annual budget (million baht)**									
		1	2	3	4	5	6	7	8	9	10
3 years	1. Development of QRNG, QR, QS, BQC in the system BOC	60	12	11							
	2. Build SPS and SPD system	20	6		3						
	3. Build/improve the lab infrastructure	35									

	4. Development of Integrated Optical Circuit with polarized light	30	10	8							
	5. Develop LMI	45	12	8							
6 years	1. Develop the capability of QRNG, QR, QS, BQC, LMI in the BOC				35	5	3				
	system 2. Increase the qubits in the SPS				35	5	3				
	system to 18 qubits 3.				3	5	5				
	Develop high potential SPD 4. Create Optical Chips, control system and Bringing light into OWC				35	5	11				
	5. SPS on OWC				10	5	5				
	6. SPD on OWC				25	5	3				
	7. Developing a small-scale LMI or OWC 8.				42	5		3			
	Building a whole communication system on top of OWC and privacy amplification					20	12	10			
	9. Build/improve infrastructure for ground station/lab 10. Electronics/				11						
	optics for ground station				24	5		5			
10 years	of quantum communication systems and networks Quantum in free space or satellite system							300	70	60	60
Total annual budget (million baht)		**190**	**40**	**30**	**220**	**60**	**50**	**310**	**70**	**60**	**60**

3. ***Integrated Quantum Sensors for All***

Quantum metrology and sensing are based on physical phenomena.
Quantum states, such as quantum superposition, quantized energy levels, and/or entanglement, for measuring quantities of interest such as time, magnetic field intensity, etc. Metrology. And quantum sensing can happen in a number of ways.

The first is to use particles at the quantum level. in measuring quantum quantity (quantum quantity) or quantity Classical quantity, where particles at the quantum level can be defined by their physical energy layer states.
The quantum, fine and hyperfine structures, as well as the
Quantum superimposition and different spins

The second approach is to use quantum coherence or control coherence.
Decoherence is the property of waves to measure different quantities.

A third approach is to use quantum entanglement states to increase the sensitivity or resolution of measurable

Metrology and quantum measurements are now in practice. Examples of important quantum systems and It has been widely accepted in metrology, such as quantum superconducting devices. Superconducting quantum devices, atomic vapors such as cold atoms or Bose-Einstein condensation, and trapped ions can be used in real life, for example in making atomic clock, gravimeter, or atom interferometer, etc.

To surpass the limits of traditional measurement to significantly higher accuracy, such as atomic clocks, which can tell time with an accuracy of only one second every billion years. compared to the clock mechanical discrepancy of 1 second every 10 years. Positionable global navigation satellite systems (GNSS). Centimeter Accurate And if further development, the accuracy is in the millimeter level. It is likely that many new innovations will come out, such as automatic driving for the blind.

Quantum sensing also has great potential for many applications, such as finding that quantum sensing units. **Solid-state** quantum sensors using the properties of a diamond with a nitrogen vacancy center (diamond) can measure ultra-neutral magnetism, which can be useful for economics. Medicine in high-resolution imaging and tissue analysis May lead to innovation for use in measuring brain waves (brainwave) to understand brain function. This will lead to a more accurate translation of complex human thoughts. Using the Josephson principle and the quantum Hall effect, which provides high-precision voltage and resistance values. It gave rise to a method for measuring electrical quantities with high resolution. which is an important foundation development of electronic devices The use of quantum interference to measure the gravitational force of the Earth will be Benefits of exploring resources or warnings of geothermal changes Or the use of quantum entanglement of light in imaging to obtain additional information from the normal even in the opaque part of the object, for example, and more importantly, the metrological standard will be adjusted. To be much more precise with techniques that use quantum principles.

3.1 **Milestones & Roadmaps**

o 3 years

- Build devices and research that demonstrate quantum measurment capabilities beyond traditional measurement by measurment. From higher resolution and stability (e.g. magnetic and temperature measurements) With a diamond crystal with a nitrogen vacancy center (nitrogen vacancy center), the spintronic device Volleytronics

and resonators (spintronics/valleytronics/resonator) based on quantum properties, atomic clocks high stable light Gravitational and magnetic measurements from atomic interference. Earth's gravitational accelerometer for use in geology. (underground oil search and natural gas, earthquakes and groundwater findings) and an innovative metrology developed within the country (innovative Thailand) based on the quantum phenomenon of matter wave interferometer.

• The development of specialized technology. In addition to the application in the quantum way. can also be used in other industries or professions such as Three-dimensional microscopy for measuring the magnetic conditions in diamond crystals with Nitrogen gaps can be applied in the medical and biochemical industries and generation. Vacuum devices for atomic clocks can be applied to industrial applications. •

Research has emerged that links knowledge in quantum measurement to other innovations such as confinement systems. energy

• Building academic acceptance of quantum measurements on the global stage (global visibility) from research. quality

o 6 years

• Prototyping quantum devices suitable in size and functionality, such as sensors. Magnets small enough to be attached to an atomic force microscope used in scanning images and to make small atomic clocks to create a time network that synchronizes the whole of Thailand (Thailand). A field-scale prototype of a portable gravimeter that has been tested for use by an underground oil exploration and drilling company. natural gas or underground water supply It can be further developed into the exploration and drilling business for oil or other resources. Including having a way to create a supply chain such as

procurement of materials (materials

supply) and production of basic parts.

o 10 years

• Turning prototypes into commercial applications is a widely used quantum device, and Thailand has its own product champions, or at least one of the key components manufacturers for the quantum device. quantum device

goals and timeframes

duration goal		**Impact/challenge/confidence**
3 years	• portable gravimeter	4/5/5
	• atomic magnetometer	4/4/5
	• atomic clock (uncertainty 10-15)	5/5/5
	• resonator	5/2/5
	• NV center sensors	5/3/5
	• spintronic sensors	5/3/5
	• Silicon-photonic biosensors	5/5/3
		(average 4.3)
6 years	• compact atomic clock	4/5/4
	• Josephson junction AC voltage standard	5/4/5
	• Quantum Impedance	4/5/3
	• atomic clock (uncertainty 10-18)	5/5/5
		(average 4.6)
10 years	**Kibble** balance (uncertainty 10-8)	5/5/5
	• Commercializable integrated quantum sensors	5/5/5
		(average 5.0)

navigation map

Figure 12. Targets and guiding maps of metrology and quantum sensing.

3.2 **Application Goals** o 3-year period

In the beginning, research investment will increase the capacity of Thailand. and the resulting research will It helps Thailand gain more recognition on the world stage. That will lead to more effective cooperation. Some levels are already ready, such as energy storage systems and solar cells that are more efficient than traditional ones. Optical atomic clock system for use in Thailand standard time, Thailand, and a gravitational field detector of the world as information for geological work

o 6 years

Prototypes of quantum devices suitable in size and functionality will be used to promote There are investors and business incubators, such as making small magnetic sensors that can be used commercially. More advanced medical imaging is also expected to aid in the interpretation of brain waves. can get more complicated Having a time network will help the security of the country. and positioning in High Resolution Satellite Network (GNSS) with millimeter resolution and innovation.

Sure, but it's probably unpredictable at this point. Electrical measurements will become more accurate at a lower cost.

new business plan

o 10 years

The incubation will lead to quantum measurements and quantum sensor systems that exceed the capabilities of the systems used.

Significantly present and widely used, especially in networked formats. by preparing that

Thai Dee will allow us to have our own product or at least a component manufacturer for quantum devices.

World-class measurement of metrological standards will be possible in Thailand.

3.3 **Necessary supporting factors (Enabling Tools)**

1) micro- and nano-fabrication capabilities

2) supply of robust and low-cost components **(eg** stable lasers, optics, optomechanics)

3) facility for making **small-scale** vacuum systems

4) supply of proper materials eg high purity diamond

3.4 Quantum metrology and sensing research budget

The budget is estimated by dividing the list into two parts.

3.4.1 Budget for Infrastructure (Not including operating budget)

Infrastructure for quantum metrology & sensing	**specific budget Infrastructure** (million baht)				
	Year 1	**2nd year**	**3rd year**	**4th year**	**5th year**
1) Virtual institute management of quantum metrology & sensing group for central coordination and use tools shared between laboratories and development coordination Business (startup/business incubator)	5.0	5.0	3.5	4.0	4.0
2) Central Laboratory for Making Quantum Devices and Sensors at the nanometer level Consists of: cleanroom, cleaning system Lithography (laser writer, E-beam lithography, mask writer), metal/insulator deposition system	40.0	30.0	5.0	5.0	5.0

Infrastructure for quantum metrology & sensing	**specific budget Infrastructure** (million baht)				
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
3) Basic Optical Science Instruments and electromagnets, such as fluorescence spectrum signal analysis system, circuit High speed electronics, instrumentation electronics, photodiode and photon signal processing systems, light control units. confocal, ultrafast lasers, photon detectors, etc.	55.0	55.0	25.0	26.0	6.0
4) Specialized material preparation system such as reactive bias target ion beam deposition, RF sputtering	45.0	10.0	6.5	6.5	6.5
5) machine shop for vacuum systems and specialized parts, and electronic shop for sensor prototyping support	15.0	10.0	5.0	5.0	5.0
Total infrastructure budget (million baht)	**160.0**	**110.0**	**45.0**	**46.5**	**26.5**

3.4.2 Operation budget according to the topic of the research (quantum device) to be built.

Research topic or name Quantum device	**Budget (million baht) (Infrastructure included)**				
	Year 1	**2nd year**	**3rd year**	**4th year**	**5th year**
ion-cooled optical atomic clocks of ytterbium and Rubidium	21.0	22.0	31.0	16.0	0.0
Quantum systems in solids for measurement and quantum computers	25.0	25.0	25.0	25.0	25.0
Development and establishment of traceability in advanced materials	20.0	5.0	0.0	0.0	0.0
analysis. Central Laboratory for Making Quantum Devices and Sensors in nanometer level	50.0	30.0	20.0	5.0	5.0
Quantum Measurement of AC Electrical Quantities	15.0	29.0	6.0	25.0	5.0
research in spintronics and quantum spectroscopy, research in	60.0	20.0	20.0	20.0	0.0
the optical plane for cold quantum transport of neutral atoms in two dimensions	20.0	20.0	20.0	20.0	20.0
Earth's gravity meter (Gravimeter) at the level of accuracy at least ÿg/g=10-7	15.0	15.0	10.0	0.0	0.0
Highly accurate optical photon measurement system	12.0	5.0	3.0	0.0	0.0

Research topic or name Quantum device	Budget (million baht) (including infrastructure)				
	Year 1	2nd year	3rd year	4th year	5th year
Photon-based quantum sensors photon-based quantum sensors, and optical quantum metrology systems metrology)	25.0	15.0	5.0	0.0	0.0
Virtual institute management of quantum metrology & sensing group for central coordination and use tools shared between laboratories and coordinated development Business (startup/business incubator)	4.0	4.0	4.0	4.0	4.0
machine shop for vacuum systems and specialized components, and electronic shop for sensor prototyping support. **Total annual**	15.0	10.0	5.0	5.0	5.0
operating budget (million baht)	**282.0**	**200.0**	**149.0**	**120.0**	**64.0**

4. Education and Training in Quantum Technology

Creating quantum technologies requires a lot of science in many fields. computational complexity or the creation of delicate tools is based on a profound understanding of nature. building a structure Systematic education helps people, especially young people in the country, to learn efficiently and quickly, which is One of the factors directly related to the competitiveness of the country.

The fundamental study structure related to quantum technologies should be consistent with research in the three pillars by National Quantum Technology Network (Thailand Quantum Technology Consortium) to digest research into smaller in the form of teaching materials that can be easily understood can be developed as a commercial prototype and can be reversed can enhance the potential of conducting primary research

For the successful implementation of the National Quantum Technology Network development of tools New science and concepts That is something that must be kept alive and ongoing. While some quantum technologies are at their maturity, ready to lead the transition to practical application that industry Scientific open-ended questions are essential to both theoretical and practical learning for develop more diverse applications and for building flexibility in the evolution of quantum technology networks. In this regard, competence in both quantum mechanics and conventional mechanics is essential to Develop tools, components, materials, or even processes that enable the operation of quantum technology networks. achieves its objectives, it can be said that New scientific knowledge will give rise to new and different quantum technologies.

Go out by the opposite angle. New quantum technologies are provoking new questions that demand new answers. With new knowledge as well, the study efforts for the development of quantum technologies are full of determination to reach that goal. It also deals with other contexts in a wide range of disciplines that may change at any moment. Therefore, it is almost impossible to complete a list of all relevant topics at any one time and to open the question to an open question. There is no limit to the fields of study that can be used to solve problems, so it is appropriate. This will include research related to social and fundamental impact. Ethical in the use of quantum technology as well.

Quantum technology lies at the intersection of engineering physics. computer science and related fields, a variety of fields, training successful quantum engineers or personnel who are aware of quantum technology That should be a key objective for starting this national network of quantum technologies. In addition, there should be an opportunity for The recruitment of personnel in transferring education to schools or communities to perform coordination within the target group with Representatives from the main investigators receiving funding and general public

This target group should be aimed at having an impact on improving the physics curriculum. engineering and data science within educational institutions across the country. including university level and school level target group Should support the creation and distribution of teaching materials to cover the whole country. And there should be a program to practice skills for high school students. or graduate students, Ph.D., or post-graduate students and has invited scientific visits from abroad to provide knowledge or to work on research together

4.1 **Milestones & Roadmap** An education roadmap for quantum technology corresponds to a roadmap for each field of quantum technology, which can be summarized as follows:

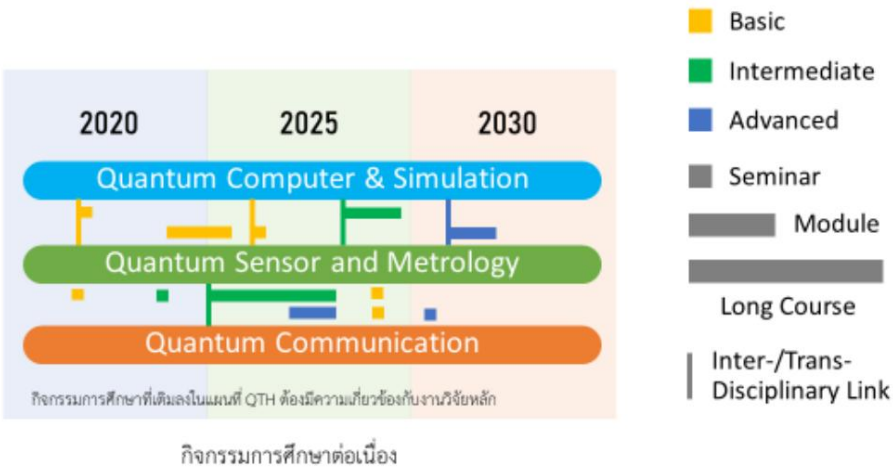


Figure 13 Examples of educational activities of the National Quantum Technology Network

In terms of developing personnel who specialize in quantum technology The design of educational structures, curriculums and subjects taught is of great importance. Including ways to promote continuous learning. Overall, it can be summarized into short-term, medium-term and long-term plans as follows.

o 3 years

- Master's degree learning courses and PhD that promotes the right skills for quantum technology.
- Activities or study topics for secondary school students.
- Organization of national seminars (national symposium) for the dissemination of technology knowledge. Quantum
- Design training seminar content for micro credentials in quantum technology.

o 6 years

- Aligning content in the secondary core curriculum to link with the development of quantum technologies • Creating a graduate curriculum for researchers. and user of quantum technology o period of 10 years

- Create a career path for those involved in quantum technology • Create organizations and activities for researcher development. and users continuously It will be a multidisciplinary or trans -disciplinary study that is consistent with innovation development. and industrial drive

Goals and road maps

duration goal		**Impact/challenge/confidence**
3 years	• Undergraduate, master's and doctoral learning courses that promote Skills suitable for quantum technology	4/4/5
	• Activities or study topics for students at secondary education	4/4/5
	• Organization of national seminars for the dissemination of knowledge. Quantum	4/4/5
	Technology • Design training seminar content for sub-credit. (micro credentials) in quantum technology	4/5/5
6 years	• Adaptation of content in the secondary curriculum to provide linked to the development of quantum technology	4/5/5

duration goal		**Impact/challenge/confidence**
	• Creation of graduate programs for researchers and users of quantum technologies •	4/5/5
10 years	Creation of career paths for technology-related people. Quantum • Create organizations and activities for the development of researchers and continuous user It will be a multidisciplinary study. or across fields in line with innovation development and industrial drive	5/5/5 5/5/5

navigation map

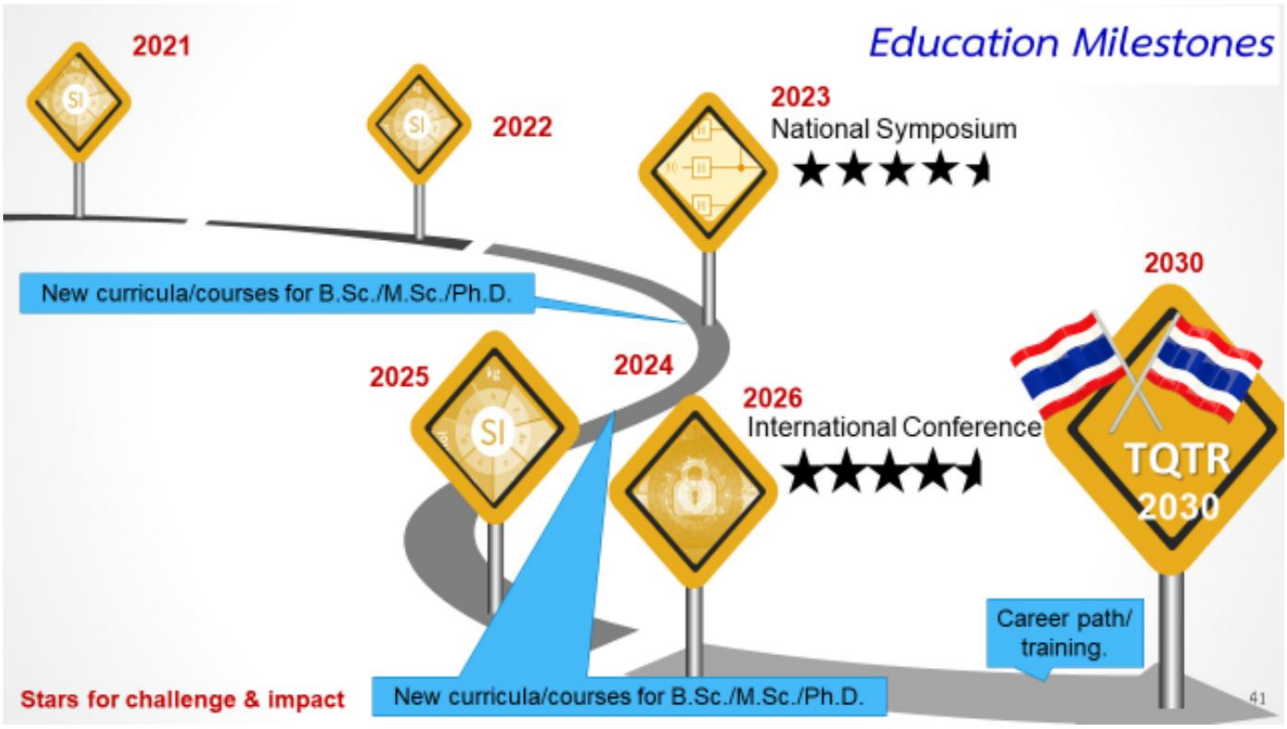


Figure 14 Goals and roadmap of quantum technology education development

4.2 Necessary supporting factors (Enabling

Tools) 1) Data storage device (server) for creating a database. and collect data

4.3 Budget

in the study of quantum technology The budget has been estimated for two parts, the building-related part.
direct manpower which may be used in the form of scholarships or registration fee and management-related parts such as organizing national/ international conferences or create a warehouse

7.4.2.1 Quantum Technology Education Budget (Only manpower)

period	**activity**	**budget (million baht)**
3 years	Manpower development: PhD students or equivalent in research projects, totaling 32 people.	80.0
6 years	Manpower Development: Ph.D. students or equivalent in research projects, totaling 64 people.	160.0
10 years	Manpower Development: Ph.D. students or equivalent in the research project, totaling 128	320.0
people, **total budget (million baht)**		**560.0**

note:

1. One doctoral student may also be substituted. 2 master's degree students or 4 undergraduate students
2. Center for Quantum Technology Singapore (CQT), spending approximately US$ 15 million or approximately 450 million baht per year, only in the education workforce section (Annual Report 2013, Center for Quantum Technologies, National University of Singapore, p. 56). In 2013, the UK National Quantum Technology Programme. Technology Program) with a budget of 50 million euros per five years, or approximately 500 million baht per year, for training and skill development in quantum technology and a budget of 16.5 million.

   Euro per five years or about 165 million baht per year for scholarships in quantum technology.

4.2.2 **Quantum Technology Education Management Budget**

period	**activity**	**budget (million baht)**
3 years	1. International academic conference 1 time	3.0
	2. National Academic Conference 3 times	3.0
	3. Educational Network Support Structure information technology, data warehouse and processing	5.0
	4. Budget management, meetings, travel, document preparation	1.0
6 years	1. International academic conference 1 time	4.0
	2. National Academic Conference 3 times	4.0
		5.0

period	activity	budget (million baht)
	3. Educational Network Support Structure information technology, data warehouse and processing	1.0
	4. Budget management, meetings, travel, document preparation 1.	
10 years	International academic conference 1 time	5.0
	2. National academic conference 3	5.0
	times 3. Educational network support structure information technology, data warehouse and processing	6.0
	4. Budget management, meetings, travel, document preparation	2.0
Total budget (million baht)		**44.0**

5. Quantum Public Outreach Developing research personnel and

disseminating quantum technology knowledge is the key to developing and promoting The development of quantum technology in Thailand However, Thailand is a middle-income country.

Strong research potential Researchers are essential to understand the problems of the entire industry. within the country and abroad to be able to create innovations that meet the needs of the country in the short and long term Central has included to create cooperation with the private sector. resulting in the development of both academic and industrial sectors together Sustainable. In addition, creating a political will to invest in research in this technology. from the government sector is also an important factor that causes sustainable development Therefore, raising public awareness from technology creators is indispensable.

5.1 **Target group and action plan**

o Research community, business and industry A

community of researchers with a well-rounded understanding of science, innovation, social science investment, and Thailand's industrial needs.

quantum computer or Between quantum crypto and blockchain technology, etc. Action plan

will support the following objectives: to connect personnel from various sectors in Thailand to join; push quantum technology Both from the industry quantum physicist including electronic engineers and computers and other related fields Emphasis is placed on domestic quantum physicists, both theoretical and experimental, to be able to link some of their work with industry.

The works that will happen to lead to linking the above sectors include Organizing online seminars for the general public, online seminars for scientists and researchers workshop International academic conferences (to enable the exchange of cutting-edge knowledge and stimulate research collaboration Between Thai researchers and foreign researchers) networking work between the education sector and industry Training camp for quantum technology education online learning resources including designing open source software for quantum computing applications. or the creation of powerful artificial intelligence Inspired by laws of quantum physics, for example.

o Government, policymakers and the general public

Creating a political will to invest in quantum technology from The government will continue to cause sustainable development. Therefore, disseminating knowledge and creating activities to see The importance of quantum technology to the government, policy sector and the general public is therefore necessary.

Upcoming work to bring participation and awareness from these sectors include dissemination of knowledge on quantum technologies through the media. whether writing articles about the community quantum in Thailand or the impact on daily life from quantum technology in Thailand through online media or newspapers. The fact that researchers have disseminated quantum technology knowledge at technology conferences in Thailand is different. such as Techsauce Global Summit, True Digital Park, various live TV interviews. In addition, the general public can be more involved through camps or quantum meetings that can be held in shared workplaces. (co-working space), etc. All of these will make these sectors realize the importance of investing in quantum technology. which is a technology that change human society in the future

5.2 **Necessary Supporting Factors (Enabling Tools)** 1) Funds and teams for organizing events, seminars within the country 2) Funds and teams from various sectors representing quantum researchers to communicate with the media accurately. must precise

3) Funding and teams for linking industry with academia Point out problems that we do together. 4) Funds and teams to push forward research cooperation between Thailand and abroad.

Goals and road maps

period	target	Impact/challenge/confidence
3 years	• Raising awareness and basic knowledge about Quantum Technology • Public and Political Motivation (public and political wills) • Build a research ecosystem for the research community and stakeholders.	5/5/4 5/5/4 5/4/5
6 years	• Activities to promote joint investment between public and private sectors in promoting and developing research.	4/4/5
10 years	• A link to bring research results to industrial expansion and national technology development.	5/4/5

navigation map

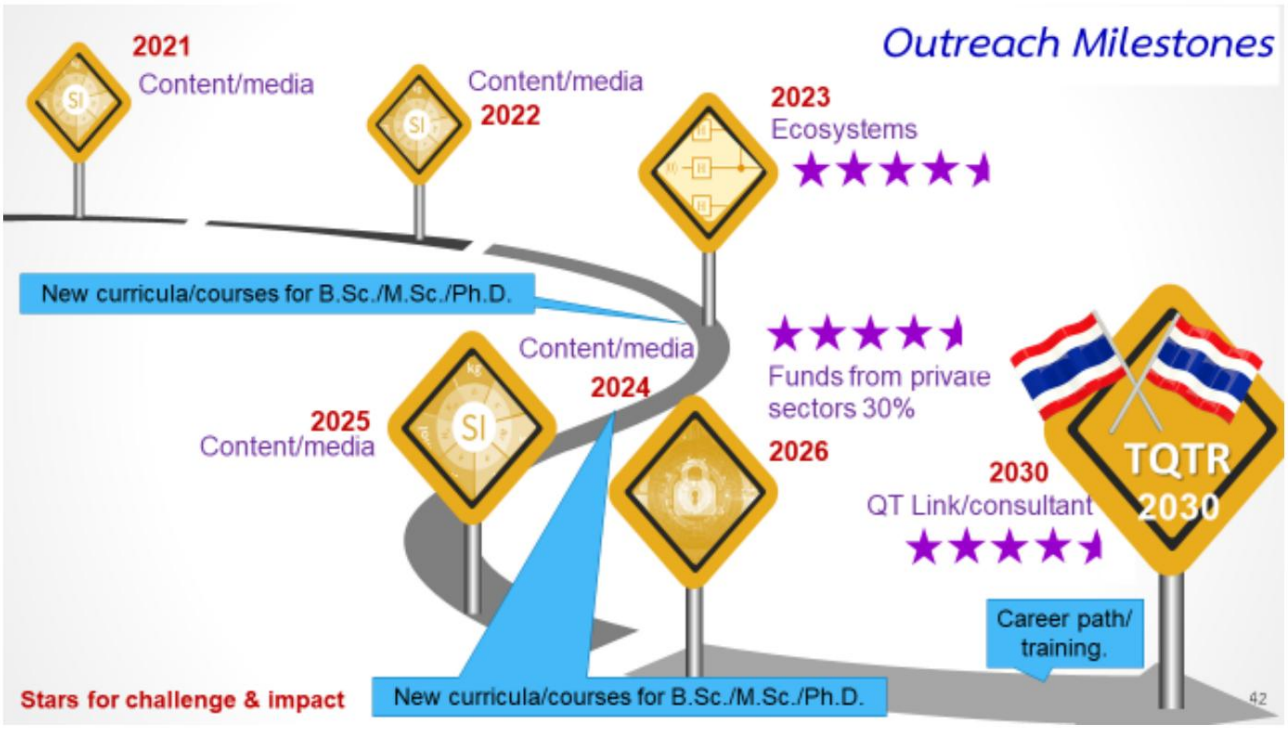


Figure 15 Targets and roadmap for public dissemination

5.3 Budget

period	activity	budget (million baht)
3 years	• Make media and content for public dissemination. • Training to educate the public. • Do workshops according to user level 5 times a year.	45.0 (7.0 + 38.0)
6 years	• Make media and content for public dissemination. • Training to educate the public. • Do workshops according to user level 5 times a year.	60.0 (15.0 + 45.0)
10 years	• Make media and content for public dissemination. • Training to educate the public. • Do workshops according to user level 5 times a year.	90.0 (20 + 70)
Total budget (million baht)		**195.0**

6 engineering jobs

To make the development of quantum technology possible quickly and efficiently. quantum scientist

A lot of engineering technical support is required from quantum engineers, such as part molding, design.

electronic circuit experimental control Including the use of research results to create a prototype (prototype) for commercial production.

commercial or industrial use

engineering physicist , scientist with in-depth knowledge of functional systems

Quantum can be scientifically researched and developed for these systems, for example. Maintaining the quantum state

(quantum coherence) and quantum control (quantum control) and can communicate the needs.

Techniques with quantum engineers to lead collaborative research solutions

Quantum engineer , a new breed of engineer with basic knowledge of quantum experiments.

Problem solving for quantum research in engineering and have in-depth knowledge of the sciences that are essential to solving research problems.

Those, such as electrical engineering electronic engineering, computer engineering, materials engineering, including nanoengineering, to

Bring modern engineering technology to apply, whether in terms of design. Making equipment or controlling

quantum operating system

6.1 Target group and action plan

Fundamentals of quantum engineering will be useful for the development of quantum technologies. by building a foundation Production and development of advanced engineering equipment Promote relationships between scientists and engineers and produce new generation of engineers who can apply knowledge in modern industries. Whether in the field of quantum technology or other fields and can be extended to the creation of commercial product prototypes.

Because there are many types of quantum operating systems. such as the atomic system superconducting system and spin systems in solids. The early stages of quantum engineering will require Emphasis is placed on laying the foundation for important research in technologies that are not yet available in Thailand. especially the technology that can be used Can be applied to a variety of quantum operating systems. such as forming workpieces at the nanometer level circuit manufacturing high frequency in the microwave region design of a control system for

quantum experiments, etc., for medium and long term Developing a strong research foundation along with the development of operating systems Different types of quantum in parallel, the basis of quantum engineering can solve new and specialized problems. in a specific quantum system And it is an opportunity for Thailand to own these specialized technologies.

6.2 Application *Goals* o 3-year period

Education and scientific research

o 6 years

Optimization and quantum advantage in solving important problems in science, economics and in industries such as cryptosystems, election auditing, lotteries and 'proof of stake' cryptocurrencies

o 10 years

Solving problems in quantum chemistry, novel materials and drug designs and full engagement with clients in major target industries.

goals and timeframes

period	target	Impact/challenge/confidence
3 years	• An important research foundation in a technology not yet available in Thailand that can support a wide range of quantum operating systems, such as nanoengineering infrastructure/laboratories for nanoscale fabrication. infrastructure to build	

period	target	Impact/challenge/confidence
	optical device Infrastructure for building electrical devices and microwave etc. • Uncomplicated necessary equipment for conducting technology experiments. Quantum and able to support quantum operating systems. variety, such as diode-replaceable lasers, measuring devices high resolution optical frequency • Quantum Engineers Group who have specialized knowledge	
6 years	• Sophisticated Necessary Equipment for support operating system Specific quantum, such as laser systems with long wavelengths specific and highly stable Photonic chip system, circuit board high speed microwave control	
10 years	Prototype of quantum technology innovation owned by Thailand • Commercial equipment prototypes for quantum research • A prototype for targeted industries, startups.	

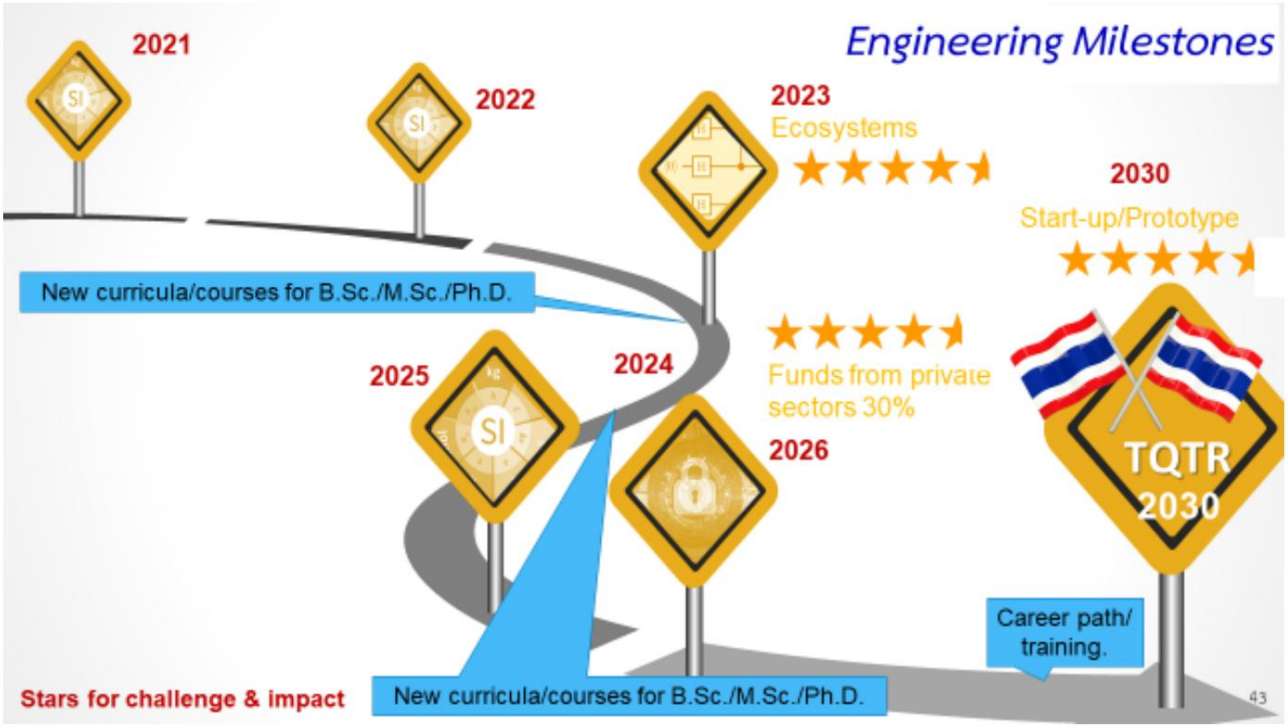


Figure 16. Engineering targets and roadmaps that support quantum technology research.

6.3 Necessary supporting factors *(Enabling Tools)*

1) Nano Engineering Infrastructure/Laboratory for the creation of nanometer-scale workpieces

2) Infrastructure for building optical devices

3) Infrastructure for building electrical and microwave equipment

4) A network of researchers made up of quantum scientists. and a quantum engineer

5) Educational training courses that can lead to the production of quantum engineers

6.4 Budget

in the engineering department The budget is set through the Project Management Unit (PMU).

where sub-projects can be accessed in the form of equipment requests which the engineering team will build The

budget has been estimated for two parts, one is the cost of raw materials. and the cost of operations

6.4.1 Budget for Engineering Work (Raw Materials)

period	**activity**	**budget (million baht)**
3 years	Develop simple essential equipment for conducting experiments in quantum technology.	55.0
6 years	Developing complex equipment and produce innovative quantum technology prototypes Produce	30.0
10 years	innovative quantum technology prototypes for targeted industries, startups. and bring various assistive devices that are produced to create a network of technological ecosystems Quantum	46.0
Total budget (million baht)		**131.0**

6.4.2 Budget for engineering work (operation fee)

period	**activity**	**budget (million baht)**
3 years	Develop simple essential equipment for conducting experiments in quantum technology.	30.0
6 years	Developing complex equipment and produce innovative quantum technology prototypes Produce	30.0
10 years	innovative quantum technology prototypes for targeted industries, startups. and bring various assistive devices that are produced to create a network of technological ecosystems Quantum	46.0
Total budget (million baht)		**106.0**

7 Application of Quantum Technology for National Development

Prosperity of Thailand)

The application of quantum technology is the key to developing and fostering the development of the technology. Quantum in Thailand and is a key element in this quantum technology development plan. because in addition to improve quality of life and increase work efficiency It was a public demonstration of the benefits. of new age quantum technology which will raise awareness in society and encourage cooperation in research with the private sector and between relevant agencies. For Thailand, in addition to strengthening research potential network researchers Research in quantum technology still needs to understand industrial problems both within and outside the country in order to be able to create innovations that meet the needs of the country in the short term. and long-term cooperation between many holistic and private sector resulting in the development of both academic and industrial sectors together sustainably It may be interpreted in two ways: (1) fundamental research for the development of specific quantum technologies aimed at put into

practice For example, the production of quantum sensors to measure the amount of toxins in the blood, or the creation of quantum algorithms to solve water management problems, etc. (2) developmental research. (research and development: R&D) to bring quantum technology already in research network

or in the market come to create a work piece that meets specific needs, such as using a measuring unit from a meter quantum science To create a device to measure air pollution (such as PM2.5) with high accuracy and fast processing.

Both approaches are important in and of themselves. Therefore, it should be done in parallel with research on quantum technology in all 3 pillars. In addition, these 2 research approaches are challenging and affect the economic and social development of the country. Thailand in many dimensions Initially, researchers must clearly identify the problems that apply quantum technologies and must prepare relevant quantum technologies in time. and clear benefits In the future when quantum technology has developed widely will make the parts of equipment using quantum technology cheaper. applied research will be a greater role in commercial Therefore, it is necessary to prepare the user. through education and manpower development simultaneously

7.1 Target groups and operational plans o

Research communities, communities of researchers in various fields such as medicine, pharmaceuticals, materials science, agriculture, etc., who are interested in applying quantum technology to their research. o Business sectors and industries interested in applying Or build a prototype of quantum technology from Research results and commercialization

The action plan will support the linking of personnel from different sectors. many research groups join in pushing quantum technology Especially in the industry, agriculture, transportation and public health sectors that see application. Quantum technology is obvious.

7.2 *Application Goals* o 3-year period Application of quantum technology in other fields such as pharmaceuticals, agriculture Examples of research problems are: • Development of photonics technology for agricultural and food industries • applications of metrology and quantum measurement for precision agriculture and safe in food

• The study of quantum phenomena in biological systems • The creation of an artificial photosynthetic system for Thai economic crops o 6-year period

Demonstration of increasing productivity or production efficiency using quantum technology, such as

• New agricultural products and food using photonics technology.

• Reduction of production costs by more than 30% • Increase of crop quality by more than 25% • Production stability

• Environmentally friendly technology

• The creation of a new photosynthetic system • New technology for food safety that increases food safety by more than 80% • Advanced technology for real-time health detection.

o 10 years

Create a Thai farming system and food production, marketing and new business

goals and timeframes

duration goal		**Impact/challenge/confidence**
3 years	• Choose a problem and create a research framework for application. Quantum technology in other fields such as pharmaceuticals, medical agriculture, banking	

duration goal		Impact/challenge/confidence
	• Study a pilot possibility. (feasibility) to Applications of quantum technology in interested fields • Develop quantum technology for applications based on Objectives in the field of interest	
6 years	• Demonstration of using quantum technology to increase productivity or increase efficiency • Develop the application of quantum technology into workpieces. or a clear process can be extended system	
10 years	• Build highly efficient systems using quantum technology. such as agriculture, food production, marketing and new business	

navigation map

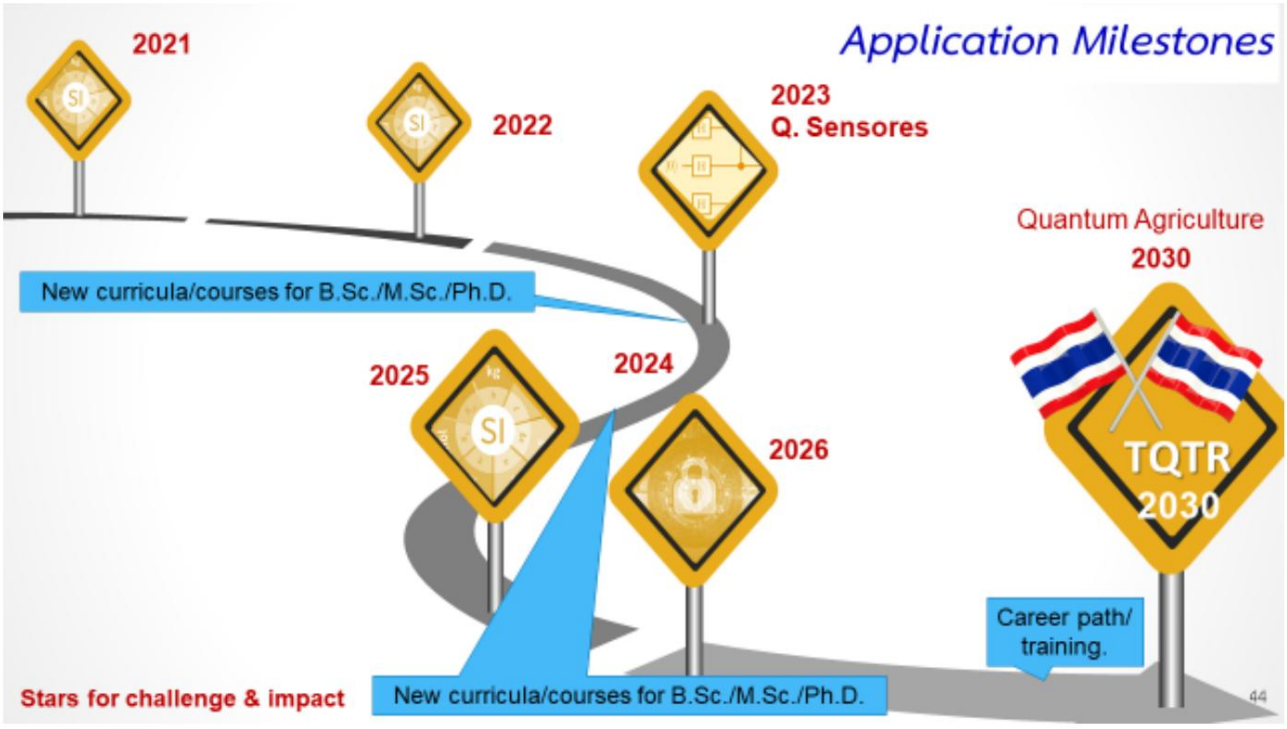


Fig. 17 Goals and roadmap for the application of quantum technology

7.3 Necessary supporting factors (Enabling Tools)

1) Quantum sensors

2) Algorithm or quantum computing process

3) Integration software

7.4 Budget

in the application section The budget will be the cost of materials and expenses, which may be for many projects.

7.4.1 Budget for material costs for research on the application of quantum technology.

Duration	**Activity**	**budget (million baht)**
3 years	• Optical, electrical, magnetic and electronic materials. in technology development Quantum for purposeful applications in fields of interest	130.0
6 years	• Develop complex level necessary equipment. and produce innovative technology prototypes. Quantum for targeted applications	190.0
10 years	• Extending the prototype system. or a demonstration set for applying quantum technology in each branch according to the target	300.0
Total budget (million baht)		**620.0**

7.4.2 Budget for research on the application of quantum technology

Duration	**Activity**	**budget (million baht)**
3 years	• Analytical tools Data collection Technician wages Research assistant wages •	75.0
6 years	Analytical tool costs data collection, technician wages, research assistant wages • Fees for academic conferences and build an expanding network	75.0 50.0
10 years	• Analytical tools data collection, technician wages, research assistant wages • Fees for academic conferences and build an expanding network • Prototyping system expansion costs or technology application demonstration Quantum	75.0 50.0 65.0
Total budget (million baht)		**390.0**

Appendix B *Glossary*

1 abbreviation and full word

Abbreviation	***full word***
AI	artificial intelligence bulk
BOC	optic circuit
DNA seq.	DNA sequencing
ESPS	entangled single photon source
FT	fault tolerant
GNSS	global navigation satellite systems global
GPS	positioning system half wave plate
HWP	long distance super
LDSS QKD	secure quantum key distribution light-matter interface medical diagnostics
LMI	magnetic optical trap noisy
Med. Diag.	intermediate scale quantum
MOT	device nuclear magnetic
NISQ	resonance nitrogen vacancy optical waveguide circuit
NMR	quantum […] quantum technology
NV	application quantum
OWC	computing quantum communication
Q. […]	quantum key
Q. App.	distribution quantum random numbers
Qcom	generator quantum
Qcomm	simulation quantum software
QKD	quantum technology quantum bit
QRNG	quarter wave plate single photon detector single
Qsim	photon source Thailand
Qsoft	quantum technology
QT	consortium Thailand quantum
qubit	technology
QWP	roadmap
SPD	
SPS	
TQTC	
TQTR	

Appendix C Related Organizations

1) Office of the Science Research and Innovation Promotion Commission (TSRI)

2) Office of the Higher Education Policy Council National Science Research and Innovation Program (NSTDA)

3) National Research Agency (NRCT)

4) National Innovation Agency (Public Organization) (NIA) 5) Agricultural

Research Development Agency (Public Organization) (ARDA)

6) Health Systems Research Institute (HSRI) 7)

Manpower development capital administration and management unit and scholarships for the development of higher education institutions research and Create Innovation (PCC)

8) Capital Administration and Management Unit for Enhancement of National Competitiveness (KorKhor.)

9) National Institute of Metrology

10) Geo-Informatics and Space Technology Development Agency (Public Organization)

11) Synchrotron Light Research Institute (Public Organization)

12) National Astronomical Research Institute (Public Organization)

13) National Electronics and Computer Technology Center (NECTEC), Science and Technology Development Agency National (NSTDA)

14) Technology Center for National Security and Commercial Applications (NSD), Science Development Agency and National Technology (NSTDA)

15) Northern Science and Technology Park **(SteP)**

16) Center of Excellence in Physics

17) Chulalongkorn University

18) Mahidol University

19) Suranaree University of Technology

20) King Mongkut's University of Technology Thonburi

21) Prince of Songkhla University

22) Thammasat University

23) Chiang Mai University

24) Khon Kaen University

25) Kasetsart University

26) Burapha University

27) Mahanakorn University of Technology

28) King Mongkut's University of Technology North Bangkok

29) Ubon Ratchathani University

30) Naresuan University

Appendix D Reference Documents

1 A. Acin et al, The Quantum Technology Roadmap: a European Community View. New J. Phys. (2018) 20, 080201

2 R. Dumke et al, Roadmap on quantum optical systems. Journal of Optics (2016), 18 (9), p.093001.

3 V. Giovannetti, S. Lloyd, and L. Maccone, Advances in quantum metrology, Nature Photonics. (2011) 5, 222–229.

4 P. Zoller, T. Beth, D. Binosi et al, Quantum information processing and communication strategies. report on current status, visions and goals for research in Europe, Eur. Phys. J.D. (2005) 36: 203. (preprint revised version 2016)

5 ARDA Report, A Quantum Information Science and Technology Roadmap, Part 1: Quantum Computing, http://qist.lanl.gov (Document LA-UR-04-1778)

6 ARDA Report, A Quantum Information Science and Technology Roadmap, Part 2: Quantum Cryptography, http://qist.lanl.gov (Document LA-UR-04-4085)

7 C. Caves, A Quantum Information Science and Technology Roadmap, eds. R. Hughes and T. Heinrichs, (Advanced Research and Development Activity, 2004).

8 Quantum Technologies Flagship Final Report, High-level steering committee (28 June 2017)

9 Frontier Research & Innovation: Quantum Technology (30 September 2019)