A Report on CO₂ Utilization Technologies Assessment in China

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CO₂ utilization (CCU) technologies refer to the industrial and agricultural utilization technologies that apply physical, chemical or biological functions of CO₂ to produce products with commercial value, which can reduce emissions compared to like products or similar processes. CO₂ utilization technologies must be used in industrial and agricultural production, rather than purely natural processes. These technologies can directly utilize CO₂, bring economic benefits, and reduce CO₂ emissions. This report is a systemic assessment of the role, significance, potential and benefits, current situation and challenges of CO₂ utilization technologies, and early stage opportunities of and deployment suggestions for China.

I. Background of the Assessment and Technological Orientation

i. CCU can break the bottlenecks of CCS, which has high energy penalties, high costs and high risks.

With emissions reduction pressure mounting internationally, CCS is regarded as one of the pillar emissions reduction methods in the future because it enjoys great CO₂ emissions reduction potential. Yet it is also criticized sometimes since it is energy-intensive, costly and risky. The development of CCS hindered, the international community set their eyes on CO₂ utilization technologies, start to explore the feasibility of offsetting the incremental cost of CCS with economic benefits brought by CO₂ utilization, and try to develop relevant CO₂ utilization technologies to provide engineering and project experiences for CO₂ storage so as to reduce energy consumption and risks. Currently, CCU has become a widely recognized stepping-stone on the way towards the ideal CCS technology that can realize massive CO₂ emissions reduction.
ii. There is no systemic assessment of CO₂ utilization technologies to date.

With an aim to improve CCS and reduce its cost, the international community has switched its research focus towards economically efficient CCU. In 2011, GCCSI issued the report *Accelerate the Development of CCS: Industrial Utilization of Captured CO₂*. According to the report, the revenues brought by the utilization of captured CO₂ can make up for part of the CCS cost so as to facilitate the development of CCS that enjoys massive emissions reduction potential. Since 1990s, the R&D of utilization technologies has been on the rise in the scientific and technological community, and there have been more and more research outputs and international platforms for academic communication. Developed countries like America, Britain, Australia and Canada have not only recognized CCUS’s importance in CO₂ emissions reduction, but also set their eyes on the considerable technology market, and pushed forward the R&D and commercialization of CCU technologies. For example, America has announced an investment of 106 million dollars into the development of CCU technologies including mineralization, algae to biofuel or chemicals (CO₂-AB) and production of polycarbonate ester (CO₂-CTPC).

Currently, the assessments of CCU technologies in the world are mostly based on direct emissions reduction capacity. In 2005, the IPCC issued a special report on CCS, which assessed the mineralization and industrial utilization of CO₂, and came to the conclusion that they would not produce obvious effect on direct emissions reduction. In July 2013, the IEA issued the updated CCS Roadmap, which pointed out that utilization
technologies had a limited capacity for emissions reduction, and therefore was not highlighted.

Developing CCS for the purpose of advancing CCS, and taking direct emissions reduction capacity as the sole assessment criterion both show the idea of the international community that the only value of CO₂ utilization technologies is emissions reduction. It ignores the economic, social and environmental benefits brought by utilization technologies and the indirect emissions reduction realized through the replacement of coal by clean energies recovered with the help of CO₂. Therefore, the above-mentioned conclusion does not provide significant guidance for China.

iii. Accurately Assess CO₂ Utilization Technologies Based on National Conditions

The correct assessment and positioning of CO₂ utilization technologies should be based on our national conditions, emissions reduction potential (especially substitutive emissions reduction potential) in our country, and its contribution to multiple goals of economic development and environmental protection. China is in an important phase of industrialization and urbanization, and our basic national conditions including the economic structure and energy mix are a lot different from those in developed countries. The fact that China is rich in coal but poor in oil, natural gas and uranium determines that the assessment and positioning of CO₂ utilization technology should be different from that in developed countries:

a. Attention should be paid to the substitutive emissions reduction capacity of CO₂ utilization technologies. China’s energy mix is dominated
by coal and the heavy industry takes up a big share in the economic structure. Although some CO₂ utilization technologies cannot isolate CO₂ from the atmosphere forever, they can help recover green energies to replace coal and other fossil fuels, thus enjoying great substitutive emissions reduction capacity in China.

b. Contribution to various goals related to China’s economic development should be taken into consideration. Apart from CO₂ emissions reduction and climate mitigation, other contributions of CO₂ utilization technology should also be noticed. In particular, it can enhance the recovery of energy resources, promote industrial development and improve energy utilization pattern.

c. We should view CO₂ utilization technology as a strategic technical reserve. Many CO₂ utilization technologies are part of CCS. The development of utilization technologies can facilitate the transition towards CCS.

Based on the stated considerations, this report presents a comprehensive assessment of various utilization technologies. It explores the potential contribution of utilization technologies to social and economic development, alleviation of resource and energy constraint, greenhouse gas emissions reduction and other goals, evaluate the current status and development trend of these technologies, analyze their technical bottlenecks, barriers and development needs, and put forward some suggestions for the development of CO₂ utilization technologies in China. Based on different subjects and principles, CO₂ utilization technologies in this report are divided into three categories (geological utilization, chemical utilization and
biological utilization) and five fields (energy efficiency enhancement, mineral resources recovery efficiency enhancement, synthesis of organic chemicals, synthesis of inorganic chemicals and production of consumer goods).

II. Development Potential and Benefits

CO₂ utilization technologies can deliver such multiple benefits as ensuring our national energy security, improving the environment, reducing emissions, creating new sources of economic growth, cultivating strategic emerging industries, enhancing national competitiveness, and promoting the sustainable development of the society.

i. Great Emissions Reduction Potential

a. The theoretical emissions reduction potential of CO₂ utilization technologies in China is huge.

With maximum resource supply and maximum market capacity, the theoretical emissions reduction potential of CO₂ utilization technology is expected to be 5.078b t/y in 2020 and 5.357b t/y in 2030.

b. Based on the current development status of CO₂ utilization technologies, they will play an important role in emissions reduction in the coming two decades.

It is estimated that by 2020, there will be a series of large-scale industrial CO₂ utilization facilities that can reduce CO₂ by 49.79m t/y, and create an industrial output of 120.9b Yuan/y.
By 2020, the CO₂ emissions reduction in the three major production fields, namely CO₂ to synthesized gas / liquid fuel (CO₂-CDR/CTL), CO₂ to methanol (CO₂-CTM), CO₂ to organic carbonate ester and high polymer materials (CO₂-CTPC), is expected to exceed 40m t/y. And the emissions reduction capacity of enhanced oil recovery (CO₂-EOR) and CO₂ to carbonate and inorganic materials (CO₂-CTC) is expected to reach 8m t/y. Other CO₂ utilization technologies are still under research in laboratories, so it is difficult to estimate their applicability and emissions reduction potential.

It is expected that by 2030, major CO₂ utilization technologies will have been commercialized, with an estimated CO₂ emissions reduction capacity of 200m t/y, and an industrial output of over 300.8b Yuan/y.

By 2030, energy efficiency and recovery enhancement technologies including CO₂ to synthesized gas / liquid fuel (CO₂-CDR/CTL), CO₂ to methanol (CO₂-CTM), CO₂ enhanced oil recovery (CO₂ EOR) are expected to reduce CO₂ emissions by 125m t/y; and the emissions reduction capacity of CO₂ to organic carbonate ester and high polymer materials (CO₂-CTPC) and CO₂ to carbonate products and materials (CO₂-CTC) will reach about 25m t/y. Other CO₂ utilization technologies will also contribute to emissions reduction.

c. With strengthened policy and investment support, CO₂ utilization technologies will be able to contribute more to emissions reduction at an early date.

If we can promote the R&D and demonstration in unconventional ways and create a more enabling market environment, over 20 CO₂ utilization technologies that are still in the demonstration and R&D phase will mature
quickly and be applied in production, which means they can play bigger roles. In this scenario, the following goals may be achieved:

It is expected that by 2020, larger-scale industrial CO$_2$ utilization facilities will be built, with a CO$_2$ emissions reduction capacity of 250m t/y and an industrial output of 375.6b Yuan/y.

By 2030, major CO$_2$ utilization technologies will have been commercialized, with a CO$_2$ emissions reduction capacity of 880m t/y and an industrial output of 904.1b Yuan/y.

**ii. Considerable Economic Benefits**

CO$_2$ utilization technologies can bring considerable economic benefits. The end products of these technologies are of various types with high added-value. CO$_2$ utilization technologies can enhance the recovery efficiency of energy resources, extract rare mineral resources, and enhance crop output. They can also synthesize with other substances to become chemical materials, chemicals, biological and agricultural products and other necessary consumer goods.

**Prediction based on the current development status of CO$_2$ utilization technologies shows that these technologies will bring China considerable economic benefits.**

Energy recovery efficiency enhancement CO$_2$ utilization technologies are expected to realize an output of roughly 5.8b yuan/y in 2020, and 45.2b yuan/y in 2030 if the market share of these technologies is 10%.
As to mineral resource recovery enhancement technologies, their industrial demonstration projects are estimated to realize an output of over 30m Yuan, and over 700m Yuan in 2030.

The products of CCU technologies to produce organic chemicals are mostly chemicals that are in great demand (like methyl alcohol) and valuable high polymer materials that are widely used. It is estimated that by 2020, industrial projects using these technologies will have an output of 105.75 billion Yuan. The number will exceed 192.02 billion in 2030 after large scale application.

The output of massive industrial demonstration projects of utilization technologies that are used to produce inorganic chemicals and process materials is estimated to be 6.26 billion Yuan by 2020, and 39.2 billion Yuan by 2030, with an expected market share of 30%.

Without benefits from carbon trade or subsidies, the industrial facilities of agricultural utilization technologies are estimated to realize an output of 900 million Yuan by 2020, and this number is expected to increase to 11.5 billion Yuan by 2030.

iii. Remarkable Environmental Benefits

CO₂ utilization technologies not only enjoy great emissions reduction potential in China but also can help to improve and protect our ecological environment. It can enhance the production efficiency of chemical and agricultural products, facilitate recycling of industrial waste, reduce industrial water consumption and ensure agriculture water supply, and reduce the discharge of sulfides, nitrides, solid waste and other pollutants. Steel slag, ardealite and red mud of aluminum oxide are all typical solid
waste from the metallurgy and chemical industries that feature high emissions, low energy efficiency and serious pollution. Mineralization of CO₂ can reduce the discharge of such waste by a large margin. It is estimated that large-scale industrial demonstration projects of CO₂ mineralization will utilize over 5 million tons of industrial solid waste in 2020, and 30 million tons in 2030 after popularization of these technologies. CO₂ utilization technologies related to agricultural production enhancement use microorganisms to sequestrate CO₂, which is totally environmentally friendly, because in the whole conversion and utilization process no chemicals are involved. They do not generate secondary pollution to the soil and are conducive to soil improvement.

iv. Summary

a. CO₂ utilization technologies have strategic significance to China because they offer a choice that can meet our multiple needs including economic development, energy security, emissions reduction and environmental protection. With accelerated industrialization and modernization, China is faced with serious challenges in energy and resource supply as well as emissions reduction. At the same time as we maintain balanced and sound economic and social development, we have to meet the emissions reduction target that carbon intensity shall be cut by 16% to 17% in the 12th Five Year Plan period, and that the CO₂ emissions per unit GDP in 2020 should be 40% to 45% down from the 2005 level. To this end, we should strike a balance between economic development, energy supply, readjustment of energy mix and CO₂ emissions reduction. Since CO₂ emissions reduction can bring economic benefits and is better to be implemented at an early date, CCUS will provide technical support for
China’s medium and long-term efforts against climate change and facilitate economic development.

b. CCUS can break the bottlenecks for regional economic development. CO₂ technologies cover a wide range and have a lot to offer to different regions. It can realize in-situ utilization of CO₂ emissions and create new sources of economic growth in the region. Geological utilization technologies can be applied to Central China, Western China and Northeastern China. Chemical utilization technologies can be applied to Eastern China and Southern China. The northwestern region, including Xinjiang, is China’s important energy base, but it has been suffering from water shortage in energy recovery and economic development. We can produce substitute natural gas (SNG) in this region and transmit the gas from the west to the east through pipelines. The high concentration CO₂ emitted can be used to displace deep saline water and is then stored underground. The saline water, after treatment, will become industrial water. In this way, not only can we increase the natural gas supply, we can also solve the water shortage in the region. CO₂ utilization technologies can break the resource constraint in some parts of China, and help to bring about leapfrogging development.

c. The development of CO₂ utilization technology will give birth to new industrial forms. Some CO₂ utilization technologies can share capture and transport system and integrate products and energies to jointly bring down the cost and energy consumption. For example, integrating chemical utilization technology with renewable energy technology can store low grade renewable energy in the form of chemical energy, breaking the wall between chemicals and energy. The integration of different technologies will lead to development of interdependent industrial parks. And the rapid rise of these
technology-backed, market oriented low-carbon industries will attract private capital and create a new situation featuring diversified investors and operation forms.

III. Current Situation, Prospect and Early Stage Opportunities of the Technologies

i. Current Situation of the Technologies

The output of scientific research in the area of CO₂ utilization technologies has been rising by the year, but more is in the basic research field rather than in the engineering field, which shows that R&D in China is still focusing on fundamental problems and key technical problems.

Most of CO₂ utilization technologies have not been commercialized in China yet, so their emissions reduction potential has now shown. Currently, the total emissions reduction of all CO₂ utilization technologies is only about 100,000t/y. These technologies create an industrial output of 500m Yuan/y, and they only generate profits under extremely favorable conditions.

Among geological utilization technologies, only enhanced oil recovery (CO₂-EOR) and enhanced uranium ore leaching (CO₂-EUL) have come close to or reached commercial level. Other technologies are still under basic research or pilot test. Currently, among the energy recovery enhancement technologies, enhanced oil recovery (CO₂-EOR) has been commercialized; enhanced coal bed methane (CO₂-ECBM) is under pilot test and its demonstration project is in the making; other technologies like enhanced gas recovery (CO₂-EGR), enhanced shale gas recovery (CO₂-ESGR) and enhanced geothermal systems (CO₂-EGS) are all under preliminary research. Among the mineral resource recovery enhancement technologies, CO₂ displacement of high-value liquid mineral resources or brine is still under
R&D; enhanced uranium ore leaching (CO₂-EUL) has entered the phase of commercial development; and CO₂ displacement of deep saline water and desalinization or CO₂ displacement of saline water (CO₂-EWR) has entered the phase of project demonstration.

Among chemical utilization technologies, several have come close to or reached commercial level. Among technologies to synthesize or convert energy products, CO₂ reforming of methane to syngas (CO₂-CDR) is under scaled-up pilot test and Carbon oxide-to-Liquids (CO₂-CTL) is under basic research. Technologies to use CO₂ to produce organic chemicals (like methyl alcohol and DMC, etc.) and organic functional materials (like degradable polymer, isocyanate/PU and PC, etc.) are under scaled-up pilot test or in the phase of project demonstration. Mineral carbonation technology has entered scaled-up pilot test and demonstration project is under way.

Among agricultural production enhancement and utilization technologies, currently CO₂ to agricultural fertilizers (CO₂-AF) has entered scaled-up pilot test and demonstration project is under way; CO₂ to food and feed additives (CO₂-AS) and CO₂ to gas fertilizers (CO₂-GF) are under technical research.

**ii. Prospect for Technology Development**

By 2020, CO₂ utilization technologies will probably have made great progress, with most technologies being industrially or commercially applied. Chemical utilization technologies are most mature. Apart from mineralization of potash feldspar (CO₂-PCM) that will be in the phase between technical development and technical demonstration, all the other technologies will probably have reached industrial application or come close to commercialization. Among biological utilization technologies, apart from
CO₂ to gas fertilizers (CO₂-GF) that will be in technical demonstration, all the other technologies will have reached or come close to commercialization. Among geological utilization technologies, enhanced oil recovery (CO₂-EOR) and enhanced uranium ore leaching (CO₂-EUL) will have been commercialized; enhanced coal bed methane recovery (CO₂-ECBM) will probably in the phase of technical demonstration; enhanced gas recovery (CO₂-EGR), enhanced shale gas recovery (CO₂-ESGR) and enhanced water recovery (CO₂-EWR) will probably in the phase of technical development; enhanced geothermal systems (CO₂-EGS) will be in the phase between basic research and technical development.

By 2030, CO₂ utilization technologies will probably have made great progress, with most technologies being or coming close to being commercialized. Most chemical utilization technologies will probably have been or come close to being commercialized; most biological utilization technologies will probably have been commercialized; and among geological utilization technologies, apart from enhanced gas recovery (CO₂-EGR), enhanced shale gas recovery (CO₂-ESGR) and enhanced geothermal systems (CO₂-EGS) that will be in technical demonstration, all the other technologies will probably have been or come close to being commercialized.

iii. Early Stage Opportunities for Demonstration and Industrialization

China has a massive amount of carbon emissions, the sources of which spread across the country with multiple geological conditions. With a well-developed industrial base, many of the CCU technologies can find good regions or sectors for implementation. Some regions can identify early opportunities for implementing multiple technologies. Taking into
consideration technical maturity, economical efficiency and regional or industrial conditions, we have come to the following conclusion:

Among CO$_2$ geological utilization technologies, enhanced oil recovery (CO$_2$-EOR) and enhanced uranium ore leaching (CO$_2$-EUL) enjoy early stage opportunities for technical demonstration. CO$_2$-EOR can be applied in major oilfields including Daqing Oilfield, Changqing Oilfield, Shengli Oilfield, Tuha Oilfield, Tarim Oilfield, Qinghai Oilfield, etc. CO$_2$-EUL can be applied in Yili Basin, Tuha Basin, Ordos Basin, Songliao Basin, Erlian Basin, etc.

Early stage demonstration opportunities of CO$_2$ chemical utilization technologies include the application of CO$_2$ to Dimethyl Carbonate (CO$_2$-CTD) in solvent, gasoline additive, lithium-ion battery electrolyte, etc., the application of isocyanate/polyurethane from indirect phosgene-free synthesis process (CO$_2$-CTU) in bulk engineering plastics, coal chemical industry, natural gas chemical industry, etc., the application of CO$_2$ to Polycarbonate/Polyester (CO$_2$-CTPC) in electronic devices, communications, medical apparatus and instruments, CDs, packaging, optic instruments, etc., the application of CO$_2$ to poly butyl diacid glycol ester (CO$_2$-CTPES) to substitute general-purpose plastics to be used in plastic films, packing materials, biological materials, etc., and the application of mineral carbonation in the building materials industry.

Early stage demonstration opportunities of CO$_2$ biological utilization technologies include the application of CO$_2$ to agricultural fertilizer (CO$_2$-AF) in agriculture and the application of CO$_2$ to food and feed additives (CO$_2$-AS) in the production of food and health care products.

China has massive CO$_2$ emissions sources, but they concentrate in energy-intensive and highly-polluting thermal power industry, iron and steel
industry, cement industry and coal chemical industry. These four industries account for over 90% of CO₂ emissions in China. But these four industries are also the cornerstone of China’s rapid economic development. Based on the current R&D status and demonstration outcome of CO₂ utilization technologies, the technologies will play a big role in these industries. They will help to optimize the industrial structure, enhance competitiveness and drive the development of relevant industries, thus realizing low-carbon, environment-friendly and sustainable development. Therefore, in future technical development, we suggest that emphasis be put on the following new industrial clusters combing CO₂ utilization technologies and the four above-mentioned industries:

- Cluster of thermal power generation, CO₂-EOR, and water-soluble mineral output enhancement
- Cluster of coal chemistry, CO₂-ECBM, chemical conversion of CO₂ and carbon recycling
- Cluster of iron and steel production, mineralization, microalgae and ecological agriculture

IV. Challenges for the Development of CO₂ utilization technology in China and Suggestions for the Deployment of Related Technologies

i. Major Challenges

a. Technical Challenges

The theoretical foundation of most technologies is yet to be shored up; breakthroughs are yet to be made in key technologies, especially ensuring
safety and stability in geological utilization, low-cost hydrogen production, high-performance catalyst, exclusive reactor and energy-efficient conversion technology in chemical utilization, and high-quality algae selecting and low-cost separation technology of biologically sequestrated CO₂ in biological utilization.

b. Challenges in Policies and Institution and Information Sharing

The current management mechanism for scientific research cannot handle well the interdisciplinary and cross-sectoral nature of CO₂ utilization technologies, and a platform for technical innovation and public test is lacking, preventing enterprises and R&D institutions from sharing their resources, data and information. There is no systematic database or technical standard system in this area. A database of large CO₂ emissions sources, an information library of CO₂ utilization potentials and an information system of matching CO₂ emissions sources and sink are yet to be established.

c. Challenges in the Industrialization of Utilization Technologies

Given that CCU technologies have high applicability, enterprises shall play a leading role in their development. However, with the huge investment needed and uncertain revenues, enterprises are not motivated under the current incentive mechanisms. In addition, the infrastructure arrangement for the popularization and commercialization of the technologies and the industrial coordination mechanism have not been established; the infrastructure planning and sharing mechanisms for CO₂ emissions source and sink matching, transmission pipelines or others are not defined; the
assignment of cost, benefits, responsibility and intellectual property is not clear.

ii. Suggestions for Relevant Deployment

Most CO₂ utilization technologies do not directly generate net profits through products. Even the most mature ones like enhanced oil recovery (CO₂-EOR) and enhanced uranium ore leaching (CO₂-EUL) can only generate profits under extremely favorable conditions. Therefore, the development of CO₂ utilization technologies needs policy support. The government should pay more attention to it, and push forward its R&D and popularization in unconventional means.

Since 2006, 16 government agencies including the National Development and Reform Commission, Ministry of Science and Technology, Ministry of Finance, Ministry of Foreign Affairs, Ministry of Industry and Information Technology, and Ministry of Land and Resources have drafted and issued more than 10 national policies and development plans. These plans recognize the importance of CO₂ utilization technologies strategically, and should be made more specific, operationalized, executable, pilottable and replicable. Since the beginning of the 10th Five Year Plan period, under the support of the 973 Program, 863 Program and National Science and Technology Support Program, there have been 36 projects related to CCUS, and half of them are related to CO₂ utilization technologies. However, current CCUS R&D activities are stand-alone activities in silos, so it’s necessary to integrate them strategically to achieve synergies.

Following suggestions are given based on the above-mentioned conditions:
a. Initiate a special science and technology program on CO₂ utilization. Improve top-level design and arrangement and set up a CO₂ utilization technologies innovation program and a strategic alliance for CO₂ utilization technologies innovation. Add a CO₂ utilization theme to the resource and environment section in the 863 Program and highlight the importance of CO₂ utilization technology in national energy and environment strategy.

b. Establish a coordination mechanism for science and technology and capture early stage opportunities. Optimize the overall system for CO₂ utilization technologies innovation, promote the coordination of technical innovation and industrial policies and management measures, and coordinate and mobilize relevant departments and local resources to organize and implement special technical projects.

c. Build a national strategic emerging industry of CO₂ utilization. Include CO₂ utilization as a component of the energy-efficient and environment-friendly industry and grant it relevant supporting policies. Set up policy mechanisms including fiscal subsidies and industrial coordination to support the development of CO₂ utilization technologies. Explore to establish special funds for CO₂ utilization technologies and explore the feasibility of including it into carbon trade. Initiate research on the CO₂ cyclic utilization mechanism among power, coal, oil and chemical industries and enterprises and form a pattern where various industries push forward the system building in a concerted manner.

d. Develop a development roadmap for CO₂ utilization technologies. Initiate medium and long-term development forecast for CO₂ utilization technologies and draw a development roadmap for CO₂ utilization technologies that is suited to the development stage of China and incorporate
international perspectives. Identify key scientific and technical problems in CO₂ utilization technologies, encourage innovation in the technologies with different focus at different stages, and translate CO₂ utilization technologies into productivity.

e. Explore and establish a national R&D platform for CO₂ utilization technologies. According to the *Medium and Long Term Plan for Key National Science and Technology Infrastructure (2012-2030)*, we should explore the building of infrastructure for CO₂ capture, utilization and storage so as to provide technical support for global climate mitigation. We should explore and initiate the infrastructure building for CO₂ utilization at an early date, integrate the resources of enterprises, research institutions and universities to support the theoretical research of CO₂ utilization and provide technical support for global climate mitigation.

f. Set up the CO₂ utilization assessment system and relevant standards. Analyze whole-process material flow and set up a CO₂ emissions assessment system of CO₂ utilization technologies. Establish relevant standards, guidelines and guides for CO₂ utilization based on existing international standards and demonstration projects in China, so as to provide guarantee for technical innovation in China.

g. Enhance international cooperation and capacity building. China should take the initiative in forming an international organization on CO₂ utilization, establish a knowledge system and shorten the R&D cycle by sharing knowledge. We should bring China’s strong CO₂ utilization technologies into the international market and widen their application worldwide.