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Technology roadmap study on carbon capture, utilization and storage in China

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HIGHLIGHTS

- A technology roadmap for CCUS development in China from 2010 to 2030 is presented.
- Sound data and analysis in combination with expert workshops are used.
- Critical technologies in CCUS are identified.
- Priority actions of all stages are identified and proposed.
- Guidance and recommendations for CCUS RD&D are provided.

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ABSTRACT

Carbon capture, utilization and storage (CCUS) technology will likely become an important approach to reduce carbon dioxide (CO_2) emissions and optimize the structure of energy consumption in China in the future. In order to provide guidance and recommendations for CCUS Research, Development and Demonstration in China, a high level stakeholder workshop was held in Chongqing in June 2011 to develop a technology roadmap for the development of CCUS technology. This roadmap outlines the overall vision to provide technically viable and economically affordable technological options to combat climate change and facilitate socio-economic development in China. Based on this vision, milestone goals from 2010 to 2030 are set out in accordance with the technology development environment and current status in China. This study identifies the critical technologies in capture, transport, utilization and storage of CO_2 and proposes technical priorities in the different stages of each technical aspect by evaluating indices such as the objective contribution rate and technical maturity, and gives recommendations on deployment of full-chain CCUS demonstration projects. Policies which would support CCUS are also suggested in this study.

1. Introduction

Increasingly, global climate change has become a major threat to the sustainable development of the human race. Mitigating climate change by reducing greenhouse gas emissions has become a hot issue in the international community. China is now the largest CO_2 emitter in the world and CO_2 emissions arising from coal burning account for approximately 80% of total industrial carbon emissions (BP, 2010). China's energy structure will still be dominated by coal in the near term (IEA, 2007). Continuous development of China's economy is needed to improve people's living standards, but will also increase CO_2 emissions leaving no doubt that China will be faced with more severe challenges in emissions reduction. Moreover, China is becoming increasingly dependent on imported oil. Currently over 50% of China's oil is imported (NBS, 2007; IEA, 2009). Carbon capture, utilization and storage (CCUS) is a relatively new technology that can realize low-carbon utilization of fossil fuels on a large scale and is conducive to optimizing energy consumption structure and ensuring energy security while reducing CO_2 emissions. Therefore, CCUS will likely become an important strategic technical option in reducing CO_2 emissions and ensuring energy security for China.

As a responsible developing country, the Chinese Government has been actively responding to global climate change. The importance of the emerging technology of CCUS for CO_2 emissions reduction for China has been made clear in many of its science and technology political documents which actively support research

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and development (R&D) of CCUS. It is proposed in *the National Medium-and-Long-Term Program for Scientific and Technological Development* (2006–2020) "to develop high-efficient, clean and near zero emission fossil energy utilization technologies" in the critical research areas of advanced energy technologies. It is also clearly stated in *China's Scientific and Technology Actions on Climate Change* that the development of CO_2 capture, utilization, and storage technology is an important aspect of controlling emissions and slowing down climate change. In *the National 12th 5-year-plan on Science & Technology* released in July of 2011, the development of CCUS technology was addressed in the sections on *Promotion of Environmental Protection and Energy Conservation Section*, and *Addressing Climate Change*.

Technology roadmaps are increasingly used for identifying obstacles and opportunities facing the development of new energy technologies. In order to centralize limited manpower, and material resources, and in order to master the capacities of CCUS full-chain project design, construction and operation by 2030, China needs to develop its CCUS roadmap for research, development and demonstration (RD&D). This paper proposes a technology roadmap for phased goals for CCUS development, making clear the priority actions for all stages and linked activities, encouraging technology breakthroughs in key bottlenecks, putting forward RD&D of CCUS technology in a logical manner, and promoting the building of relevant secure systems.

2. Roadmapping process

2.1. The roadmap approach

A technology roadmap is one of the most commonly used methods to forecast technological trends and to develop research, industry, government or other strategic goals of a particular technology (Placet and Clarke, 1999). The main role of a technology roadmap is to support technology management and planning (Phaal et al., 2004). It has attracted attention from both researchers and policy makers in the last decade. Several prominent researchers have played a great role in CCUS technology roadmapping with the intention to identify the potential challenges of deploying CCUS technology and develop strategies to address them. Global scale roadmaps to accelerate the deployment of CCUS have been formulated by The Carbon Sequestration Leadership Forum (CSLF, 2006), the European Technology Platform for Zero Emission Fossil Fuel Plants (ZEP, 2006), and the IEA (IEA, 2008). National scale roadmaps were also constructed to facilitate CCUS technology development in Australia (CO2CRC, 2004), the USA (NETL, 2006), Canada (CETC, 2006) and the UK (Gough, et al. 2010). Complementary to these roadmaps, the technology roadmap in China aims to consider CCUS technology in a Chinese context and take into account the key country specific issues which may impact on its development, such as economic and social development, dislocation between source and sink, the storage potential, geological conditions, and population density.

With the purpose of sharing experience and integrating knowledge across the entire CCUS chain (capture, transport, utilization and storage), the workshop to formulate the technology roadmap brought together a diverse group of stakeholders and experts in CCUS research from government departments, industry, scientific institutes and Non-Governmental Organizations (NGOs). Given the unique national conditions of China, this roadmap proposes a vision for the development of China's CCUS technology and provides feasible and affordable technical options in response to climate change by promoting sustainable economic and social development. It also proposed phased development goals from the present until 2030.

2.2. Methodology

Guided by the IEA roadmap (IEA, 2010), to make the roadmap effective, the workshop holders gathered information needed for the roadmap and supported the experts with sound data and analysis to establish current baseline conditions. Background information and baseline data were collected at early stages. A modified Delphi method has been adopted during the roadmapping process. The traditional Delphi study (Linstone and Turoff, 1975) adopts an iterative approach to developing a consensus view on a set of questions or statements, presenting results of previous rounds to a single group of experts. It usually needs four iterations to reach consensus with a long time of each period. Experts are not allowed to discuss with each other in the traditional Delphi method which was not appropriate for roadmapping which requires consideration of how to integrate the various CCUS technologies. The modified method that applied to this study was combined with questionnaire methods and discussion methods. It was designed to operate in two distinct phases with the survey results informing the follow-up group roadmapping workshop. The process was as follows.

We interviewed a variety of stakeholders in the field of CCUS to design a questionnaire which included key issues in CCUS technology development, analysis of macro CCUS development trends, CCUS technology status and barriers, security issues brought about by CCUS, necessary laws and regulations, financial support requirements, and enterprise opportunities, obstacles and challenges in the development of CCUS. Next, eight authoritative experts were consulted to improve the questionnaire. A preliminary investigation was done with 30 stakeholders who were randomly selected from the interviewees. The results show that the questionnaire was reasonable. One hundred and twenty "expert" stakeholders were selected from the database of CCUS project reviewers from China's Ministry of Science and Technology to ensure that the whole CCUS area was represented. Then, relevant background material and questionnaires were provided on-line to these stakeholders for the first round survey of which 91 responded and fed back their results. After excluding seven invalid questionnaires (i.e., had a leakage or zero variance in the questionnaire; repeat questionnaire), we included 84 samples in our analysis. Based on the survey results, the questionnaire were redesigned and sent to the participants for the second round survey together with the first round results. The first two rounds of questionnaires were completed before the workshop to not only reach consensus at the workshop but also to inform the participants with background data and survey results. In this way, the participants would have enough time to consider the divergence in views within the expert stakeholder group and to prepare for the follow-up workshop. Final iterations were made during the workshop. Participants could discuss and debate freely in the workshop sessions and after that, voted in an anonymous way to ensure their opinions would not be affected by other authorities. The results from the last round session were fed back to the next round session until the experts reached an agreement.

Accelerated by discussions in the workshop and thanks to the authoritative experts who participated in designing the questionnaire, the entire process only took three rounds of iterations for the expert stakeholders to reach consensus, while the experts reached a consensus by voting only one round in the workshop section. In this study, questions were cross referenced and required quantitative responses. Mean value, standard deviation and coefficient of variation were calculated after each round. The consensus was achieved when the Kendall coefficients of concordance was higher than 0.7 at the 95% level of significant (Schmidt, 1997).