Abstract

Coal is central to China’s continued economic growth and CCS is one of the most promising technological solutions to curb the CO$_2$ emitted from the continued use of coal. This paper introduces some areas of recent R&D on CCS in China and focuses, in particular, on the Near Zero Emission Coal (NZEC) project, a China-UK CCS initiative. NZEC is being undertaken in three phases, with the current project comprising the first phase. The ultimate aim of NZEC, following Phase 3, is to have constructed and operated a coal-fired power plant with integral CCS in China.

In this paper, some of the early progress made in NZEC Phase 1 is described. Launched in November 2007, the objectives of Phase 1 are to build confidence in CCS and to explore technology options for demonstrating coal-fired power generation with CCS in China. The Phase 1 partnership of nine leading UK organisations and 20 from China demonstrates the strong collaborative working relationship that exists between China and the UK, at all levels, to develop CCS as a key climate change mitigation technology. Apart from NZEC, China is involved in several national and international CCS initiatives and some of these will be touched upon in this paper.

The success of the 18-month first phase will, to a large extent, be measured against its contribution to increasing CCS capacity in China and against strengthened links between Chinese and British experts. Activities designed to raise capacity are described.

Keywords: CCS; CO$_2$ capture, CO$_2$ storage, cooperation; NZEC
1. Introduction

China’s growing economy has been fuelled predominantly by coal and, as a result, CO₂ emissions have virtually doubled in the past 10 years, see Figure 1[1]. According to the IEA, China was forecast to overtake the United States as the world’s leading emitter of CO₂ and, indeed, did so during 2007[2] though China’s cumulative and per capita emissions are far lower. In 2006, China’s total energy-related CO₂ emissions were 5,680 million tonnes, compared with the USA’s 5,750 million tonnes[3].

![Figure 1: Total CO₂ emissions in China from 1980 to 2005](image)

With concerns for the rising concentrations of CO₂ in the atmosphere and for the potential impact on its economy, the Chinese government are paying close attention to global climate change. A series of policies to control CO₂ emissions and to protect the environment has been enacted. In 2004, the National Development and Reform Commission (NDRC) released the ‘China Medium and Long Term Energy Conservation Plan’[4]. This plan was the first to cover energy conservation for the medium and the long term that had been formulated and issued by the Government of China. To promote the development and utilisation of renewable energy, to improve the energy structure, to diversify energy supplies, and to protect the environment, The Renewable Energy Law of the People’s Republic of China was passed by the National People’s Congress in February 2005[5]. In September 2007, NDRC released the ‘Medium and Long-term Development Plan for Renewable Energy’[6]. According to this plan, China’s renewable energy will account for 10% and 16% of total energy consumption by 2010 and 2020, respectively. For the purpose of promoting energy conservation, improving energy efficiency and cutting the emissions of pollutants, the Energy Conservation Law was amended in October 2007 and put in force on 1 April 2008[7]. In 2006, the Ministry of Science and Technology, the China Meteorological Administration, and the Chinese Academy of Sciences released China’s first-ever National Assessment Report on Climate Change[8]. The assessment provided a scientific basis for formulating global climate change policies and for participating in negotiations with the United Nations Framework Convention on Climate Change (UNFCCC). In June 2007, China’s National Climate Change Programme was published by the Chinese government[9]. It was the first national climate change programme that represented the objectives, principles, priority areas and policies of dealing with climate change.

Having implemented regulation, moving towards a low-carbon economy requires the application of a number of practical measures. There is no single or simple solution. The portfolio of measures includes, for example, raising the levels of energy efficiency practised, increasing the installed capacity of renewable energy technologies and of nuclear plant for power generation, and reducing the emissions of CO₂ from the combustion of fossil fuels. A technique that has the potential to provide deep cuts in CO₂ emissions from fossil fuels is carbon capture and storage (CCS). CCS is best suited to large industrial point sources of CO₂, including power generation and large energy consuming industries, such as oil refining, iron and steel, cement and chemicals production.
CCS involves capturing the CO$_2$ either before or after combustion and storing it for the long-term in deep geological formations, such as saline aquifers and depleted oil and gas fields. The three main methods for capturing CO$_2$ are post-combustion capture, pre-combustion capture and Oxyfuel capture. As part of the storage process, the captured CO$_2$ can be used to enhance hydrocarbon (oil, gas or coalbed methane) recovery. CCS technology can reduce CO$_2$ emissions from coal-fired power stations and from other large point sources by up to 85% or even higher. Together with energy efficiency and other low carbon technologies for power generation and industrial processes, CCS can make an important contribution to greenhouse gas mitigation. In addition, it has the potential to allow the continued use of fossil fuels, enhancing China's energy security without damaging its climate security. The Chinese government is paying close attention to the development of CCS technology, is encouraging the engagement of Chinese organisations through R&D to demonstration and is supportive of international collaborative programmes on CCS.

This paper will describe some of the R&D being taken forward in China, some of the international collaboration taking place and then describe some recent progress on Phase 1 of the joint UK-China Near Zero Emissions Coal (NZEC) project.

2 Recent progress on CCS in China

2.1 Post-combustion

Many institutes are concentrating effort on CO$_2$ separation using chemical absorption\cite{10}. Institutes including Nanjing University, Tsinghua University, Beijing University of Chemical Technology, Zhejiang University, Tianjin University, Huazhong University of Science and Technology and the Chinese Academy of Sciences have already been engaged in substantial research activity in this area. The main focus has been on the development of new solvents with high absorption capacity and low regeneration energy consumption. In July 2008, the first demonstration project in China, separating 3000 tonnes/a of CO$_2$ from coal-fired flue gas, was commissioned at the Gaobeidian thermal power plant in Beijing\cite{11}. In this project, undertaken jointly with Australia's CSIRO, amines are being used to chemically absorb the CO$_2$, with a recovery efficiency of more than 85%. It is planned for the CO$_2$ to be used in the food service industry.

Membrane absorption technologies are expected, in time, to be more efficient than conventional CO$_2$ separation processes\cite{12}. The Chinese Academy of Sciences, Dalian University of Technology, Beijing Mining Institute, Tsinghua University, Zhejiang University, Tianjin University, Nanjing University of Science and Technology are each engaged in R&D in this area. New membranes are under development, with the effects of operating conditions on various materials being tested.

Adsorption is based on the intermolecular attraction between the gas and the active sites on the surface of adsorbent. Adsorbents under investigation in China, for example at the Nanjing Chemical Institute, include zeolites, active carbon and molecular sieves. The China University of Mining Technology is investigating the potential for anthracite as the basis for preparing active carbon for separation of CO$_2$\cite{13}. With its extended surface area, the active carbon is expected to have a large capacity for uptake of CO$_2$.

2.2 Oxyfuel combustion

Many universities are investigating oxyfuel combustion. Southeast University and Huabei Electricity University have studied the characteristics of pulverized coal combustion, thermodynamics analysis and pollutant control in O$_2$/CO$_2$ mixtures\cite{14}. Based on the characteristics of coal combustion and pollutant emissions under oxyfuel conditions, Tsinghua University have reported a decrease of SO$_2$ and NOx emissions\cite{15}. Huazhong University of Science and Technology have investigated desulphurization under oxyfuel combustion in a vertical tube electrical heating reactor and established a small oxy-fuel combustion test system\cite{16}. Zhejiang University are looking into oxyfuel combustion in circulating fluidized bed combustors\cite{17}.

2.3 Pre-combustion

Many Chinese organizations consider IGCC to be an attractive clean coal technology for power generation, particularly if CCS is to be applied. They believe its potential for gas clean-up integration, leading to inherently low
emissions and lower costs, make it an ideal candidate for the future. In 2004, the Huaneng Group proposed the ‘GreenGen’ project, where R&D would be undertaken on IGCC with hydrogen production, hydrogen power generation and CO₂ capture [18]. The project was divided into three phases, with the final objective to build a 400MW demonstration plant in Tianjin. The first phase, comprising construction of a 250MW unit, is underway at present.

2.4 Chemical-looping combustion
Chemical-looping combustion is a novel process for CO₂ capture. The Chinese Academy of Sciences’ Institute of Engineering Thermophysics have studied chemical looping combustion technology using NiO/NiAl₂O₄ as the oxygen carriers [19]. On the other hand, Southeast University have looked into using Fe₂O₃ and Fe₃O₄ as the oxygen carriers, with coal and biomass as fuels [20].

2.5 CO₂ storage
As yet there is a lot of uncertainty regarding the magnitude of secure, geological storage capacity for CO₂ in China and estimates vary widely. Research continues, however, and storage via enhanced oil recovery (EOR) and enhanced coalbed methane recovery (ECBM), storage in deep saline aquifers, and storage in depleted oil and gas fields is being examined. The Institute of Rock and Soil Mechanics at CAS has estimated the potential CO₂ storage capacity in 24 main saline aquifers, 68 main coal seams and 46 main oil and gas fields to be at least 140 Gtonnes, 12 Gtonnes and 7.8 Gtonnes, respectively [21-23]. The total geological storage capacity in China was provisionally estimated at around 196.2 Gtonnes CO₂, which is a factor of 27 greater than China’s CO₂ emissions in 2006 [24]. The Institute of Geological and Geophysical Research at CAS has developed a model to calculate CO₂ solubility in a water-salt-gas system, which will facilitate estimation of CO₂ solubility in such systems as CO₂-H₂O-CaCl₂ and CO₂-seawater [25].

Aquifer storage accounts for a large proportion of the potential CO₂ geological storage capacity in China. The Institute of Rock and Soil Mechanics have investigated the distribution of deep saline aquifers that may be suitable for CO₂ storage [21]. Sites located in the North China Plain, the Sichuan Basin and southeast of the Junggar Basin are considered most ideal. Sites in east and southeast China are also potential storage candidates. In the southeast coastal area and in South China, their investigations show that CO₂ can be stored in the brine aquifers of sedimentary basins located on the continental shelf.

CO₂ can be used for EOR, which can increase the oil field production and also prolong the oil field production period. Since the 1960s, several EOR projects have been implemented by PetroChina and the China National Offshore Oil Corporation (CNOOC). Experimental activity is ongoing in the Daqing, Shengli, Liaohe and Zhongyuan oil fields.

In a similar manner, ECBM recovery can be used to store CO₂ whilst improving methane recovery. At present, there is only the single CO₂-ECBM Recovery Project in China, which is located at the Qinshui basin of Shanxi province [20]. This project, implemented by the China United Coal Bed Methane Corporation, Petromin Resources and the Alberta Research Council, is investigating whether CO₂ will enhance the production of coal bed methane from deep unmineable coal seams.

3 NZEC project

The UK-China Near Zero Emissions Coal (NZEC) initiative (www.nzec.info) addresses the challenge of increasing energy production from coal in China and the need to tackle the growing CO₂ emissions. In September 2005, during the UK’s presidency of the EU, the EU-China NZEC agreement was signed at the EU-China Summit, as part of the EU-China Partnership on Climate Change. The agreement has the objective of demonstrating advanced, near zero emissions coal technology through CCS in both China and the EU by 2020. The UK-China bilateral NZEC project was developed in support of this wider agreement.

Under the NZEC initiative, an ambitious three-phase approach is envisaged with the ultimate ambition of constructing and operating in China a demonstration of a coal-fired power plant with CCS. Phase 1 will explore the options for demonstration and build capacity for CCS in China. Phase 2 will carry out further development work on
capture and storage options, leading to Phase 3, which aims to construct and operate a coal-fired demonstration plant with CCS before 2020.

Phase 1 of the project is supported by funding of up to £3.5 million (US$6 million) from the UK Government’s Department of Energy and Climate Change (DECC). The project is being taken forward in partnership with the Chinese Ministry of Science and Technology (MOST). It involves a two-year work programme to help build capacity for CCS technology in China, to develop stronger links between Chinese and British experts, and to study a range of options for early demonstration of CCS. Phase 1 began formally in February 2008 and is due to complete during autumn 2009. Its scope was developed through extensive consultation between the UK and Chinese partners, which included a major international workshop in Beijing in July 2006.

In brief, the objectives of NZEC Phase 1 are to:

- Build capacity in China on CCS.
- Model the future energy requirements of China and the role that CCS might play.
- Undertake techno-economic case studies of CO2 capture technologies.
- Assess and evaluate the storage potential for CO2 and to undertake preliminary screening of potential sites suitable for geological storage of CO2.
- Build confidence in CCS. Describe technology options for a CCS demonstration in the context of China. Report broadly on non-technical issues – policy, social, economic, legal, regulatory and finance – that will have a bearing on both short and longer-term deployment of CCS.

Knowledge sharing with other international CCS initiatives is being undertaken as far as possible, particularly those with support funding from the European Commission. The partners within the NZEC consortium are shown in Table 1.

| UK partners                  | Chinese partners                      |
|------------------------------|---------------------------------------|
| AEA – lead UK partner       | ACCA21 – lead Chinese partner        |
| Alstom Power                | BP-Tsinghua CEC                       |
| British Geological Survey   | IGG CAS                               |
| BP                           | IET CAS                               |
| Cambridge University        | Centre for Energy and Environmental Policy Research |
| Doosan Babcock              | CUCBM                                 |
| Heriot Watt University      | CUP (Beijing)                         |
| Imperial College            | CUP (Huadong)                         |
| Shell                       | DESE, Tsinghua University             |
|                             | DCE, Tsinghua University              |

Table 1: NZEC Phase 1 partners

3 NZEC progress

NZEC Phase 1 is divided into 5 work packages.

3.1 Work package 1: Knowledge sharing and capacity building

A key success factor in NZEC will be the degree to which knowledge is shared and communicated among the partners and, through them, to the wider community. This is essential to create a better understanding of CCS and of its potential as a CO2 mitigation technology. The target audience comprises academics, industrialists, policy-makers and the general public, all of whom will be important in supporting the development of CCS and its wider
deployment in China. Studies in the technical work packages will contribute to capacity building, reinforcing the skills, experience and contacts for the Chinese partners to champion the cause of CCS in China.

A host of methods are in use to share knowledge and build capacity. Websites, newsletters, specialist publications and training materials are in preparation or have been implemented. Five Chinese researchers have been invited to study in the UK for a year, with Cambridge University, Cranfield University, Heriot Watt University, Edinburgh University and Imperial College, each a host institution. Support has been made available for the attendance of many others at key international conferences and events.

An interim ‘public’ NZEC event was held in Beijing in October 2008, with a final dissemination event planned for autumn 2009.

3.2 Work Package 2: Future energy technology perspectives

In Work Package 2, the potential for CCS to reduce emissions from the Chinese power generation sector and other energy intensive sectors is being assessed. An energy systems analysis exercise is being undertaken to provide a perspective on the energy technologies that may be deployed to meet the energy needs in China to 2050. The energy sector in China will be analysed, with a detailed investigation undertaken of the various technologies and fuels deployed at present. MARKAL modelling will be used to predict the technologies and fuels that may be deployed to meet China's future needs. The potential for CCS to reduce CO₂ emissions to the atmosphere, and the cost and impact of deploying CCS will be examined.

3.3 Work Package 3: Case Studies for Carbon Dioxide Capture

Work Package 3 focuses on investigating the technology options for capturing carbon from coal fired power stations and assessing which options may be the more suitable for use in a demonstration plant in China.

The objectives of WP3 are:

- To investigate the techno-economic characteristics of various carbon capture technologies, based on specific conditions of China.
- To identify whether the capture options would be deployed in the short-term, mid-term or long-term.
- To recommend the most promising cases for the CCS demonstration project. These are likely to be those technologies that exhibit lower energy requirements and lower economic penalties.

Basic conditions for use across the studies have been agreed, with a number case studies underway. Case studies will cover each of the three generic processes for capturing CO₂ from power plants, ie post-combustion, pre-combustion and Oxyfuel.

3.4 Work Package 4: Carbon dioxide storage potential

The aim of Work Package 4 is to build capacity in China for evaluating storage potential and performing appropriate first stage site characterisation for site selection. Outputs will include:

- Regional studies of potential storage opportunities in the Songliao, Subei and Qinshui Basins.
- Site-specific studies of opportunities for CO₂ storage in the Jilin and Jiangsu oilfields, with the potential for 'value-added' through enhanced oil recovery.
- Site specific study of saline aquifer storage potential in a selected area of the Songliao Basin
- Site specific study for coal in the Qinshui Basin with potential for 'value added' through enhanced coalbed methane recovery.
- Geographic Information System map of potential storage sites and large sources of CO₂ (>100kt/year) for preliminary source-storage matching.

Workshops have been held in China, where all partners have benefitted from the accumulated expertise of the representatives in the field of CO₂ storage. Project partners have gathered data and reviewed methodologies for estimating capacities.
3.5 Work Package 5: Policy Assessment and Roadmap

In this work package, a number of non-technical matters that may influence the adoption of CCS in China will be explored, with policy-makers and others consulted on CCS policy, regulatory and legal issues. Socio-economic impacts and risks will be considered, particularly where they relate to the early-stage deployment of CCS in China.

A final project report will also be completed in late 2009. Based on the outcomes from the various work packages, the intention will be to discuss the potential for deployment of CCS at the commercial scale and its potential to make deep cuts in China’s CO₂ emissions. Results presented will build confidence among the major stakeholders and enable decision-makers to make better choices on how to move towards demonstrating CCS in China in collaboration with the EU. The emphasis will be on moving towards an NZEC demonstration in China.

4 EU-supported activities in China

Other projects that are wholly or partly covered under the umbrella of the EU-China Partnership on Climate Change include MOVECBM, GeoCapacity, COACH and STRACO2. These four projects are all likely to complete before or at around the same time as NZEC. Only NZEC and COACH are wholly focused on China; the other three are targeted mainly on Europe, with a part focus on China. An important element of each of these projects, and not least NZEC, is to maintain a dialogue between the projects through formal and informal joint meetings and workshops, a number of which have already taken place.

The MOVECBM project is focused on the monitoring and verification of the CO₂ storage capacity of deep subsurface coal and possible emissions to the surface. A 2-year programme began in 2006, with the practical activity predominantly undertaken in Europe. The outcomes of the research will be used to evaluate and extrapolate the findings to other countries both within and outside of Europe, e.g., China.

The GeoCapacity project, which commenced in 2005, was to assess the European capacity for geological storage of CO₂. Further development of innovative methods for capacity assessment, economic modelling and site selection criteria were to be developed. An important element was to initiate international collaborative activities with China.

In 2006, the Cooperation Action within CCS China-EU (COACH) project began. A sister project to NZEC, COACH is also an initial stage in targeting the demonstration of nero-zero emissions coal technology through CCS in China. The structure of the project is very similar to NZEC, with the detailed work programme designed to be complementary and with minimum duplication.

The Support to Regulatory Activities for Carbon Capture and Storage (or STRACO2) project is designed to support the ongoing development and implementation of a comprehensive regulatory framework in the EU for CCS technologies. An important feature of the project is its intention to build a basis for EU-China cooperation on CCS.

5 Conclusions

The UK-China Near Zero Emissions Coal (NZEC) initiative addresses the challenge of increasing energy production from coal in China and the need to tackle the growing emissions of CO₂. Phase 1 of the project involves five major pieces of work, which collectively have the ambition to bring closer the date of a commercial-size demonstration of a coal-fired power plant with CCS in China. Experts from China and the UK are working together to progress the project to the best of their collective abilities.

Though there is extensive activity on CCS in China, a commercial-size demonstration project has yet to be established. The potential for CCS in China is high, but there is still much to do. International cooperation and government support are essential for the development of CCS in China in the short-to-medium term.
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