CHINESE ADVANCED POWER PLANT CARBON CAPTURE OPTIONS (CAPPCCO)

Project Summary

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Results from this project are presented in detail in a number of published reports and papers, including two PhD theses, as listed below. The Chinese/English web site set up during the project www.captureready.com continues to give topical information on CCS in China. A short summary of the main findings is also provided overleaf.

Dr Jia Li presents the Chinese translation of the IEAGHG capture ready report she and Dr Xi Liang prepared for the CAPPCCO project to a large audience in Shanghai in June 2009.

Publications related to the work undertaken under CAPPCCO

Xi Liang, Coal as a Lower Carbon Energy Technology: Financing Carbon Capture and Storage in China, PhD Study, Cambridge, 2009.

Jia Li, Options for introducing CO_2 capture and capture readiness for coal fired power plants in China, PhD Study, Imperial College, 2010.

Li, J., Liang, X., Cockerill, T., Gibbins, J., Reiner, D. (2012). Opportunities and Barriers for Implementing CO_2 Capture Ready Designs: a Case Study of Stakeholder Perceptions in Guangdong, China. Energy Policy.

Li, J., Liang, X. (2011). CO_2 Capture Modelling for Pulverised Coal-fired Power Plants: a case study of an existing 1GW ultra-supercritical power plant in Shandong, China. Separation and Purification Technology.

Li, J., Liang, X., Cockerill, T. (2011). Getting Ready for Carbon Capture and Storage Through a ‘CCS Ready Hub’: a Case Study of Shenzhen City in Guangdong Province, China. Energy, 36(10), 5916-5924.

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Li, J., Gibbins, J., Liang, X., Reiner, D., Jiang, C. and Liu, X., “Overview of CCS development in China””, Proc. 8th Annual Conference on Carbon Capture & Sequestration, May 4 -7, 2009, Sheraton Station Square, Pittsburgh, Pennsylvania.

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Summary (based on Li and Liang PhD Theses)

1. Options for introducing CO_2 capture and capture readiness for coal fired power plants in China (as of 2010)

The use of fossil fuel in primary energy supply is predicted to increase in the next two decades. In China, a large number of new coal-fired power plants are being constructed and it is estimated that coal will still supply over 60% of primary energy in China in 2020. CO_2 capture and storage (CCS) is therefore a promising technology option to decarbonise the Chinese energy sector while at the same time satisfying its fast growing energy demand. Making new Chinese coal-fired power plants CO_2 capture ready could greatly facilitate their subsequent retrofitting to capture CO_2 and can significantly reduce the probability of 'carbon lock-in' for the whole of their lifetime.

During the course of this study, a number of results have been found including:

1.1 CCS and CCR for gasification process

The possibility of capturing carbon dioxide through the gasification process in China was predicted to have a promising future. In this study, an investigation of the Chinese gasification industry showed that the potential for capturing carbon from gasification plant using coal as feedstock varies according to the plant's end products. Although a number of IGCC plants have been proposed in China, at the time of writing only one plant has obtained construction permission from NDRC (Greengen). Some of the other proposed IGCC plants have included a future extension of their plans to capture CO_2 by post-combustion technology at a later stage. But with the main IGCC plant's future still uncertain, the later retrofit stage may not be realistic.

Existing studies comparing the up-front spending in IGCC plants and the cost saving after retrofit shows that capture ready for IGCC plant is not an economic and technically favourable investment, because of the difficulty in matching the turbine before and after capture. If an IGCC plant investor is planning to build a carbon capture plant in the future, the proposed plant should be built as a pre-combustion capture facility from the beginning rather than be retrofitted at a later stage.

Most of the new advanced gasifiers in China are ordered by Coal to Liquid (CTL) companies, and the appropriate capture ready design for such companies will vary based on the process and liquid end product. Capture ready is already on the agenda of a company which is constructing a direct liquefaction technology plant in China (at the time of writing only one direct liquefaction plant has been authorised for construction). Some indirect liquefaction plants have also been planned to add capture equipment at a later stage. Self motivation is a strong driver in the gasification industry for CTL plants in relation to carbon capture, especially to capture ready, because the worry of the additional capture requirement in the future. Because of the high concentration and (or) high pressure of carbon dioxide in some of the streams in the CTL plants, the overall capture cost could be slightly cheaper than carbon capture from conventional power plants.

1.2 Power plant carbon retrofit potential in China

If carbon capture and storage becomes mandatory in China some early cheap opportunities exist in the gasification industry. However, conventional pulverised coal (PC) fired power plant remains the largest carbon dioxide emitter in the energy sector. Recent orders from boiler companies and other estimates by international organisations have shown that the growth in the PC industry is likely to continue over the next decades. The current Chinese policy on "increasing energy efficiency" and "closing small inefficient units" caused the industry to accelerate the change to even bigger power generation units and advanced boilers in China. Power plants with 1000MW, 660MW and 600MW units will dominate the market in the future. Consequently the next part of the study turns the focus onto the PC industry.

In order to understand the current power plant industry and the potential for CCS in China, a screening study on Chinese large size power plants was carried out using Google Earth. The clear Google images of the layouts of 75 power plants have revealed that around 50% of the existing power plants studied will be difficult to retrofit and may cause carbon lock-in in the future. This is especially true for power plants that were built relatively early in more developed areas. It will be relatively easy for some of the

plants studied to be partially (as opposed to fully) retrofitted because of the tight layout of the existing generation units. In this type of plant, the units that are built at the end of a row of units (if plants are built parallel to each other) can be more easily retrofitted without changing the layout of the plant too much.

1.3 ASPEN modelling results

An ASPEN simulation model, designed to estimate the potential changes for advanced PC plant, can be used to demonstrate possible changes that might be involved in a retrofit case. The 1000MW ultra supercritical power plant at Zhouxian, Shandong province was selected as the baseline plant, because of the large market potential for large size generation units in China. The boiler unit is one of the most common types of its scale; its general operation conditions are modelled. The retrofitted system combines the conventional power generation unit, the additional post-combustion unit and additional associated equipment. In this model, the efficiency drop is estimated to be around 6% after retrofit for a 90% capture (or 6% for a 50% capture). This simple model gives power plant owners an uncomplicated way to examine their own plant for carbon capture. A list of the equipment needed for the retrofit is also summarised for plant operators.

1.4 Capture ready in China

Retrofitting existing power plants is only one important issue to be explored in China. Planning new power plant to fit in the existing power network is another crucial challenge. Building power plants with a carbon capture ready design can help ease the problem. Firstly, site selection methodology for capture ready power plant is set out, including legislation, engineering, and external factors. The criteria used for assessing the capture ready site are provided in a checklist. When a number of sites are selected as possible candidates a spider chart can be used to rank the scoring for each site and help to make the final investment decision.

Geographically China is a large country. The differences in economic development, geological formations, eco systems and natural resources make it very hard for China to plan capture ready power plant. To simplify the problem, a regional planning (as opposed to national planning) regime is recommended in China. Guangdong Province, in the south of China is selected as an example to show the analytical process. The study shows all the power plants with a least one unit over the size of 300MW in Guangdong that supply electricity to the southern grid. An analysis linking power plant located in the Pearl River delta, the early storage potential in the Sanshui basin and planned connecting transport pipelines shows the potential of CCS in Guangdong province. In conclusion, three cluster locations are proposed for future large scale off shore storage. At the moment, five organisations in south China and two partners in the UK are working on a project on “Making Guangdong the first capture ready province in China” funded by the UK Foreign and Commonwealth Office (FCO).

1.5 Stakeholders’ interview

Building on the capture ready and retrofit engineering study done previously, an online survey on capture ready issues in China, followed by face to face interviews, was also carried out in order to get a better understanding of power plant engineers’ comments in the study results. The result found that CCS and capture ready are already relatively well established concepts among the interviewees, and post combustion capture, rather than pre-combustion capture, technology is considered more likely to be used in the first 10 demonstration projects. For the interviewees, storing carbon dioxide basically means EOR or ECBM at the moment. The stakeholders believed that capture ready is a way of attracting foreign investment and they also share the view that the additional foreign investment should be used to fund the capture unit rather than the power plant itself. The survey result also found that in order to implement capture ready, influencing the power plant project manager is as important as influencing senior government officials. They also considered access to storage sites as an important issue. More than 50% of stakeholders believed that the extra space to accommodate the capture unit should be ‘1/8 to 1/4 the size of the power plant’ (2x600MW plant were used as baseline), but 30% still selected “not sure” In their answers. The extra water consumption for the capture unit should not exceed 1/8 of the water requirement for the original plant in water shortage areas, but this was not seen as a problem in water abundant areas.

1.6 Summary of findings

To summarise, the engineering requirements and strategies to implement CCS and capture ready in China have been investigated, beginning with understanding the nature of the research question, generating the results of the modelling, analysing the results, and understanding the current status. The main findings are:

1. It may not be economic to build pre-combustion capture ready for power generation in China, but suitable IGCC sites are being considered as options for post-combustion retrofit

2. There is a high possibility of carrying out capture ready in most gasification-based chemical and coal-to-liquid plants in China

3. Capture ready in china for pulverized coal plants is important and the best way to avoid carbon lock-in

4. The similarity in Chinese PC plant designs was studied and possible layout planning and retrofit designs are set out

5. A simple ASPEN model for easy-to-use post combustion capture modelling was developed and tested

6. This study sets out a new methodology for capture ready site selection

7. It also includes GIS cluster design for Guangdong when planning future potential power plant locations

Finally the results of a survey were presented, carried out mainly with power plant engineers, on technical design for new CCR plants.

1.7 Recommendations for policy makers

More than 70% of the power plants installed in China are thermal power plants, and these are dominated by coal-fired power plants (BP 2009). The IEA has estimated that another 300GW of coal-fired power plants will be added before 2030, by which time 60% of China's electricity will be produced from coal. In order to reduce the total greenhouse gas emissions from the electricity sector in China, carbon capture and storage technology is the only solution given the current circumstance. The technology includes two elements, capture retrofit for existing power plants and making new power plants carbon capture ready.

Retrofitting existing power plants (or closing them down) is the only way to reduce current carbon dioxide emissions from coal-fired power plants. Over 80% (in terms of installed capacity) of the coal-fired power plants that supply electricity to the national grid in China have an individual installed capacities of over 1GW. If power plant retrofit becomes mandatory in the future then starting with large sites can achieve relatively greater emission cuts. Some regions also show greater potential for retrofit than others, such as regions that are closer to storage sites, have easy access to coal resource, have a population with a better understanding of climate change. For such regions, it might be beneficial to introduce the cluster concept and share some of the transport and storage infrastructure. However, a large number of power plants appear to be less attractive for retrofit from an investment point of view. Whether to retrofit or close down such plants should be decided on a case to case basis.

At the moment, there are no mandatory policies or suggested guidelines for new built power plants to be constructed in a carbon capture ready way. However, building power plants in a "ready"state is not a new concept for power plant engineers or policy makers. In the past, Chinese policy makers have seen many power plants built in a SOx ready state and currently, and currently also, in a NOx ready state, in both cases because power plant investors are aware of the environmental challenge they might face during the lifetime of the power plants. Similar to these concepts, carbon capture ready could be introduced to power plants through a bottom up process rather than a top down regulation. And the concept of partial capture should also be suggested. However, power plant investors need to be aware of such a solution before it can be rolled out nationally, as the survey in this study identified. Introducing such concepts through workshops, local unions, public or professional media is a good way of increasing awareness.

1.8 Suggestions for future research

The following section outlines some suggestions for future work in this area.

a) The Google Earth image data base should be upgraded annually, when yearly new data on the large sized plants is published by China Electricity Council (CEC). The work can help the understanding of the changes in general layout for new power plants and the technology involved (especially the cooling technology). By summarising the data and comparing the images, a better assessment of the latest plant design configurations can be generated to inform capture ready design concept developments. In addition, the trends in locations selected for new plants should be studied. For example, more plants may be being built either in coal abundant areas (aided by the very rapid development of the transmission grid) or in high electricity consumption areas. Such work will provide important data for capture ready site location planning in China, for example whether plant should built at a CO_2 storage location with good transmission grid or at an accessible site with pipeline transport.

b) Use the ASPEN simulation results based on a 600MW unit to investigate different degrees of capture for different plant operating conditions. The database of different power plant parameters could also be investigated and fed into the model. Finally, an Excel based tool could be created for such simulations to give preliminary results. The user will only need to input the boiler conditions, such as the maximum pressure and temperature for the boiler's steam flow rate, unit capacity, low pressure turbine working conditions, flue gas conditions. A list of additional equipment and its working conditions will also be required. The Excel file will then give the efficiency drop for different levels of capture. If a power plant has this tool instead of the ASPEN model, the owners can evaluate their power plant easily online, and this may help to accelerate the development of CCS.

c) Investigate the use of ammonia based solvent instead of amine based solvent in the simulation. Ammonia based solvents are calculated to have a much lower energy consumption level than amine based solvents. Ammonia is a common chemical product in China. When ammonia is used for the capture process, carbon dioxide emission reduction could be achieved in both the gasification and electricity industry.

d) The criteria for a capture ready plant site selection and design could be analysed quantitatively. More of the criteria could be calculated through a serious of mathematic equations, instead of using qualitative methods. This might result in a reduction of individual personal biases and create a better evaluation platform.

e) The survey on CCS or capture ready should be repeated each year to show changes of opinion among stakeholders. By tracing attitude changes, policy makers can better understand the situation and concerns among industry investors.

2. Coal as a Lower Carbon Energy Technology: Financing Carbon Capture and Storage in China
(as of 2009)

2.1 Overview of financing and related issues

Many of the key political, economic, social and financial aspects involved in deploying carbon capture and storage (CCS) technologies and carbon capture ready (CCR) in China have been investigated. Of course, the road to deploying lower-carbon coal technologies is long and involves many different aspects. At present (summer of 2009), there is no immediate policy incentives in place to develop CCS projects at scale in China nor to encourage CCR, but the interests and discussions of the role of CCS technologies in climate and energy policy have been growing dramatically when compared the first CCS survey in China for CCP2 project in summer 2006. One recent focus has been on CCS pilot or demonstration projects, notably the GreenGen project recent surveys for NZEC project in spring 2009 (not included here) which extends surveys to examine stakeholder views on CCS demonstration projects. Closing fossil fuel power plants earlier than schedule to build alternatives could be painful given the recent experiences of closing small units to fulfil the energy efficiency policy. If CCS is expected as an essential part of solution in mitigating global warming for the next two decades, making new plants to achieve CCR status in China is possibly a good compromise in reality.

2.2 Case studies

The case studies undertaken in this study assessed the economics of investing CCR at a new-build 600MW USCPC unit, assuming the plant is retrofittable even without CCR. The results indicate the plant will be economic under certain scenarios. To analyze the retrofitting decision, evaluate CCR and price capture option, a stochastic discount free cash flow model with retrofitting and closure options has been developed and applied. Four CCR scenarios based on the IEA CO_2 capture ready study were analysed, the more basic "essential" CCR design with floating turbine design configuration was found to be the most promising option. Both studies found the option value of retrofitting to capture is significant, and a relatively small investment in CCR may dramatically significantly reduce the chance of early closure. Another significant finding is the importance of setting multiple decisions nodes in valuing CCR, as the paper found that a scenario assuming only one decision node may significantly underestimate the value of CCR. Assuming multiple decision nodes assumption is recommended in analyzing the value of CCR and the price of capture options. From an investor's perspective, the economic viability of CCR is strongly dependent on the inputs assumptions, such as the price of CO_2 emissions reductions, fuel cost, and electricity prices. The only direct financial benefit from investing in CCR comes from the carbon market, which largely depends on the Chinese commitment at international climate change negotiation. The analysis is somewhere optimistic regarding the possibility of future Chinese efforts at reducing greenhouse gases. Aside from Chinese precautionary principle (to "store up grain against famine") and concerns for future generations, Chinese government engagement on climate change (and on CCS in particular) has grown dramatically in the past few years. As electricity price is an opportunity cost of capturing CO_2, one important limitation of the first two papers is the assumption that the current electricity pricing mechanism and despatch policy in China will continue throughout the project's lifetime. The results of the model may be invalid if deregulation of Chinese power sector or electricity market reform happens.

2.3 Stakeholder surveys

Until now Chinese power companies and governments have been reluctant to invest in carbon capture ready (CCR) technologies, because they are worried that the costs of retrofitting to capture may not be recovered by the extra revenue generated. Capture option initiative, based on methodologies originating from real option theory, offers attractive conceptual benefits in financing CCR and integrating the complex carbon capture and storage (CCS) system. Applying the capture option concept will allow a sole entity to optimise the operation of capture, transportation and storage component in CCS. Though the concept has already received great interests from CCS policymakers, academics, consultant firms and Chinese power companies, its practical applicability may require further investigation and improvement, such as solving liquidity and reverse selection problems, and designing a proper option exercise policy. Chapter 3 provides a preliminary exploration of issues in the decision making process beyond the cash flow spreadsheet. The data to support the analysis in the three papers in Chapter 3 and 4 was collected from a large number of interviews with Chinese stakeholders from 2006 to 2008. With respect to the institutional framework in China, the National Development and Reform Commission (NDRC) is currently seen as the most important institution in authorizing large-scale thermal power project, however, local governments are attributed more importance to the economic prospect and social impacts. CCS is recognised important but not yet prioritised by national governments, but the perception may change if CCS is included in CDM or China committed emissions reductions towards a certain date. In addition to the institutional framework, decision-makers' individual behavioural patterns, such as anchoring, overconfidence, naive diversification, loss aversions, endorsement effect, aversion to ambiguity and money illusions, may affect investment decisions in the Chinese power sector, based on the findings of the preliminary study presented here. Are the perceived biases primarily the results of psychological factors or institutional frameworks? The behavioural study presented here has not attempted to attribute sources of these interesting behavioural patterns, nor has it explored neither the boundaries of rationality nor the potential of applied utility theory in analysing behavioural patterns. These limitations need to be addressed in further work and only until then can the potential practical implications of behavioural finance in Chinese power sector will be more fully assessed.

In terms of longer term prospects, carbon capture and storage (CCS) is already perceived as "a necessary and important technology in combating the climate change threat" by more than half of Chinese stakeholders interviewed from 2006 to 2008. However, many stakeholders were concerned about the energy penalty associated with CCS, technological immaturity, and potential for higher electricity costs. The significant energy penalty of CCS is anticipated to be the main challenge in deploying CCS at scale in China for the next two decades, unless either or both of the following two scenarios comes true:

1. senior Chinese politicians recognised that reducing greenhouse gas emissions is more urgent than securing its energy supply;

2. globally, the security of energy supply has been addressed and the costs of energy are reduced significantly from current levels.

2.4 Lessons for CCS economic and social studies in China

The primary methodological contribution of the $_{CAPPCCO}$ work is in combing (i) real option analysis in project finance, with (ii) institutional framework analysis and (iii) behavioural finance. By applying a multi-dimensional analysis, the study seeks to provide insights into deploying CCR in China including both quantitative and qualitative elements. Some of the specific lessons relating to research design in particular include:

- A cost cash flow model is preferred in a comparison of different technologies with similar outcome (e.g. IGCC vs. PC, where both technologies reduce similar amount of CO_2, and generate identical quantity and quality of electricity), especially when revenue are highly uncertain. However, a free cash flow model should be applied to calculate the economics of CCR, the value of capture option and understanding the probability distribution of potential retrofitting timings.
- To gain insights into key decision-makers' opinions in China, face-to-face interview have been found to be more effective than telephone or online survey, because interviewees are more willing to tell the in-depth opinion, according to responses of four stakeholders consultations from 2006 to 2009. On the other hand, face-to-face surveys involve some disadvantages including: high costs, time constraints, and sometimes a reluctance to answer quantitative questions. Therefore, online surveys complemented by follow-up face-to-face interviews with selected stakeholders from online panel may be a good compromise. In addition, to ensure the data quality and higher response rates, the length of an online or telephone survey on Chinese key stakeholders in energy sector should be restricted and not exceed 20 minutes.
- With regard to questionnaire design, a combination of quantitative and qualitative is viewed as preferable for the work conducted here. Quantitative data has advantages in comparison and draw robust conclusion. Qualitative data is relatively discrete and hard to synthesize but it provides more detail insights and may not be eligible for everyone in the panel, for example only a minority of decision-makers are able to answer the consideration in authorizing an IGCC project. Ideally, because of different backgrounds and sectoral perspectives, the questionnaire form should be path dependent.
- Weighting and adjustment may be applied when comparing results from different samples. Survey methodology can affect the results, at least the depth of the data. The regional distribution of stakeholders is important demographic information which should be clearly stated, due to large regional discrepancies in China.
- Three stakeholder consultations in this study were conducted by face-to-face and telephone and in addition, an online consultations was conducted for UK-China NZEC project in early 2009 via http://www.CaptureReady.com.

2.5 Recommendations for potential CCS investors

a. Carbon Capture and Storage Pilot or Demonstration Project

- In the short term (5 years), developing CCS pilot projects in China is a more feasible strategy than proposing a commercial-scale capture and storage project. Large scale thermal power project is subject to the approval of NDRC (as discussed in paper 3), and this potentially long and complex process for authorising CCS may jeopardise the value of early demonstration. As long as CCS is not prioritized and well-understood by the Chinese governments, CCS pilots may be seen as more attractive because they may not require authorization by central government institutions (e.g. NDRC, National Energy Administration).
- Foreign investors may collaborate with local power companies and/or institutions familiar with local governments and power grids to eliminate policy and regulatory uncertainties coming from the institutional framework
- Investors may gain advantages from better understanding decision-makers' behavioural patterns, heuristics and bias. For example, more than 80% of stakeholders consider government priorities such as "large-scale" power plants, or investment in "rapidly developing regions" as being more important than traditional economic measures such as NPV or IRR, and therefore capturing a small proportion of CO_2 from large-scale thermal unit (600MW or above) in rapidly growing region sounds more promising for Chinese stakeholders. Technically, plants in a rapidly growing region are more likely to be operating better de-SOx and de-NOx facilities, and this may lower the costs of capturing CO_2 out of flue gas using a post-combustion process, but the evidence shows that economic returns on large power plants are lower than returns from medium-sized plants.
- Understanding the Chinese institutional framework may add value to project investment, for example, some investment decisions tend to be framework dependent rather than based on economic performance.
- Development of capture pilots or demonstration projects may be more likely when both average capacity load factors and coal prices are lower, because Chinese decision makers may exhibit some anchoring and overconfidence behaviour regarding their abilities to predict the future. In developing CCS projects, low load factors (utilization hours) indicates lower opportunity costs to capture while low coal prices mean low fuel costs, both of which are positive for the economics of capture units.
- The recent (2007 to 2009) CERs prices available to Chinese actors via the Clean Development Mechanism (CDM) would not compensate the full costs of capture, and therefore, public funding support is currently very important for demonstrating CCS projects. However, in the short term, the total amount of funding from Chinese government sources is very limited and mostly focuses on supporting R&D for CCS. Therefore, demonstrating commercial-scale CCS projects requires international financial sources, such as EU, multilateral banks and etc.
- Joint-ventures with local grid companies may gain advantages from electricity dispatch policy and on-grids electricity contract prices, and thereby improve the economics of the project. Electricity dispatch policy is perceived as significantly more likely to trigger revisions in economic forecast compared to carbon prices and environment protection requirements. In addition, loss aversion behaviour (exhibited by 84% of stakeholders) may trigger local shareholders to struggle for better policy for survive rather than closure if facing adverse economic situation.
- Until climate security is attached equal or greater importance as a priority by Chinese decision-makers, a proper strategy should be considered in response to national energy security and efficiency concerns from deploying CCS in China that primarily related to the energy penalty from CCS. In the short term, enhanced oil recovery (EOR) and enhanced coal bed methane recovery (ECBM) will be the preferred ways of demonstrating CO_2 storage underground, because the extra oil production and coal mining safety benefits may compensate the energy penalty concern in CCS

system. For example, if CCS projects in coastal areas with good access to imported coal, importing coal rather than purely consuming domestic coal may help the proposal.

- CCS demonstration projects should explicitly address decision-makers' worries over geological disasters, health hazards, and large-scale leakage, for example by proposing offshore saline-aquifer storage and pipeline in low population density area. Chinese decision-makers are found to be more risk averse than their EU peers in developing CCS.

b. CO_2 capture ready (CCR)

- The option value of retrofitting to capture to avoid the high costs of carbon emissions or mandatory closure at a later date is high, and thus new thermal power plants owners should consider essential CCR investments (including planning for access to potential storage site) to keep the retrofitting option (capture option) open.
- CCR may be viewed as a complementary investment to CCS demonstration or pilot projects. Investors of pilot projects may invest directly or encourage plant owners to invest in CCR next to or near the underlying capture units for the expansion of capture units and access to storage site.
- Green Investors and oil companies with interest in EOR or other geological storage methods may consider purchasing capture options (or option contracts to buy steam and capture CO_2 from flue gas) from power generation companies to motivate CCR investments.

c. CCS R&D and technology transfer

- CCS equipment or technology providers should actively participate in Chinese CCS pilot or demonstration projects to establish better market positions, through joint-venture or other commercial agreements.
- CCS R&D institutions should apply for greater financial support from Chinese government and/or foreign government sources.
- Foreign CCS technology leaders may have IPR security concerns over collaborating with Chinese technology and equipment providers, but this may be justified by market advantages gained, particularly since "produce domestically" is a main decision criterion when authorizing Chinese government projects.
- Equipment vendors providing a CCR design as a premium option in their product lines may gain a better market position in the future.

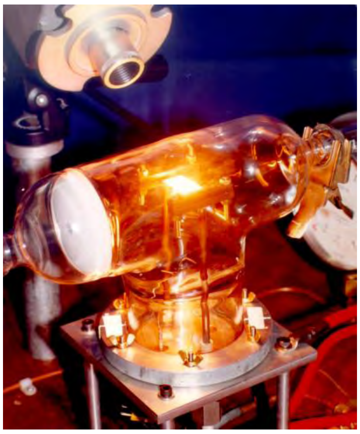
2.6 Recommendations for CCS policymakers

- Although more than 60GW of new coal-fired power plants are built annually, fitting a large number of new coal plants with CCS is unrealistic, because climate change policy is not yet as important as energy conservation or energy security policies and a large number of decision-makers remain concerned over the energy penalty of the CCS system. Promoting CCS R&D, capacity building and communicating with key decision-makers to promote CCR are therefore top short-term priorities for deploying CCS in China.
- In the medium and long term, it is important to incorporate CCS technologies into Chinese national development plans, such as the national five-year plan, because industrial stakeholders probably view projects encouraged by the national governments favourably as a result of the "endorsement effect".
- CCS communication in China should focus on key policy-makers, industrial leaders and government officials, as public perceptions, CCS legal and regulatory framework are perceived as lower priorities in deploying CCS technologies.
- Stress testing for financial pressures of future carbon emissions costs in new Chinese coal-fired power plants may encourage CCR design and up-front investment to avoid "carbon-lock in" or "mandatory early closure". As a result of their loss-aversion mindset, Chinese power companies are likely to consider retrofitting to CCS rather than "early closure".

- Setting up special CCS trading intermediates to purchase capture options, storage options will finance and optimize CCR, help integrate the complex CCS system and develop CCS technology.
- Chinese institutional framework characteristics and behavioural issues, such as anchoring, heuristic-driven behaviour, overconfidence, and loss aversion, should be considered in questionnaire design, analysis of survey results and cross surveys comparisons. For example, mentioning that CCS is written into the medium and long term national scientific development plan, before asking about support for Chinese government subsidy for a CCS demonstration project will lead more stakeholders to pick "yes" than simply asking "will you support Chinese government to subsidize a CCS demonstration project?", because of the "endorsement effect".

3. High temperature wire mesh apparatus

Technical information and specimen equipment for a high temperature wire mesh apparatus has been provided to project collaborators at the Harbin Institute of Technology. This apparatus can provide advanced coal characterisation data to support future pulverised coal combustion and gasification applications in China.



A high temperature wire-mesh apparatus heating coal at approximately 2000ºC