Financing Capture Ready Coal-Fired Power Plants in China by Issuing Capture Options

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Abstract

'Capture Ready' is a design concept enabling fossil fuel plants to be retrofitted more economically with carbon dioxide capture and storage (CCS) technologies, however financing the cost of capture ready can be problematic, especially in the developing world. We propose that fossil fuel plants issue tradable Capture Options to acquire financing. The Capture Option concept could move CCS forward politically in countries such as China, speed up CCS technology development, help Capture Ready investors diversify risk, and offer global warming investors an alternative investment opportunity. As a detailed case study, we assess the value of a Capture Option and Capture Ready plant for a 600 MW supercritical pulverized coal power plant in China, using a cash flow model with Monte-Carlo simulations. The gross value of Capture Ready varies from CNY3m ($0.4m) to CNY633m ($84.4m) at an 8% discount rate and the Capture Option is valued at CNY113m ($15.1m) to CNY1255m ($167.3m) for two of the four scenarios analyzed.

Keywords: Capture Option, Capture Ready, Carbon Capture and Storage, Climate Change, Coal-fired Electricity, China

JEL Classification: O1, O3, Q5

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List of Abbreviations

CAPM (Capital Asset Pricing Model)

CCS (Carbon Capture and Storage)

CEC (China Electricity Council)

CER (Certified Emissions Reduction)

CDM (Clean Development Mechanism)

CHNG (China Huaneng Group)

CNY (Chinese Currency: Yuan)

DTI (Department of Trade and Industry in the UK)

EAF (Equivalent Availability Factor)

EBITDA (Earning Before Interest, Tax, Depreciation and Amortization)

EIA (Energy Information Administration)

EOR (Enhanced Oil Recovery)

ETS (Emissions Trading Scheme)

FGD (Flue Gas Desulphurisation)

FY (Financial Year)

Huaneng (Huaneng Power International, Inc.)

IEA (International Energy Agency)

IGCC (Integrated Gasification Combined Cycle)

IPCC (Intergovernmental Panel on Climate Change)

LHV (Low Heating Value)

Local EPA (Local Environment Protection Administration in China)

MLR (Ministry of Land and Resource in China)

MOF (Ministry of Finance in China)

NPV (Net Present Value)

NRDC (Natural Resources Defense Council)

O&M (Operating & Maintenance)

PC Power Plant (Pulverized Coal Fired Power Plant)

ROA (Real Options Analysis)

SAT (State Administration of Taxation in China)

SC-PC (Supercritical Pulverized Coal Fired Power Plant)

SEPA (State Environment Protection Administration in China)

SERC (State Electricity Regulatory Commission in China)

Solar PV Power (Solar Photovoltaic Power)

Std Dev (Standard Deviation)

USC-PC Power Plant (Ultra Supercritical Pulverized Coal Fired Power Plant)

WACC (Weighted Average Cost of Capital)

1. Background

1.1 Background to Carbon Capture and Storage (CCS)

In October 2006, the Stern Review, commissioned by the British government, described the economic impacts of climate change, as well as the business opportunities if action is taken. According to Stern, mitigating climate change is urgent and acting now could save more money in the future, so it '*must be treated as an investment, a cost spent now and the following years to avoid the risk of serious damages in the future*' (Stern, 2006: 171). According to the International Energy Agency, fossil fuel power plants are the single largest source of carbon dioxide, accounting for more than 40% of CO_2 emissions globally, and the trend is likely to continue through 2050 (IEA, 2006). The largest increase in emissions comes from the power sector.

The US Energy Information Administration (EIA) estimates that worldwide installed electricity generating capacity will grow from 3,710 GW in 2003 to 6,349 GW in 2030, of which coal-fired power plants will contribute 1997 GW in 2030, accounting for 31% of the total electricity capacity (EIA, 2006). The growth will increasingly come from the large emerging economies of the developing world. In China alone, more than 200 GW of new fossil fuel fired power generation (virtually all coal) capacity was added from 2004 to 2006 (NDRC, 2007). IEA projects that between 2006 and 2030 China and India will produce more CO2 emissions from energy than the US, EU and Japan combined (IEA, 2007). Moreover, this is not a problem that can be ignored for many years before being addressed; as seen in Figure 1, plants built over the next decade will produce emissions for many decades to come.

Thus, carbon dioxide capture and storage (CCS) technologies, by which CO_2 is captured when generating power and injected underground for storage (as shown in Figure 2), is described by the UK Department of Trade and Industry (DTI) as '*the most promising way to stabilise greenhouse gas content in the atmosphere*' (DTI, 2003). In January 2007, the European Commission stated that CCS should be the standard in coal-fired power generation from 2020 (EC, 2007). Yet in spite of the great interest, CCS technologies are at a relatively early stage in terms of systems integration. The IEA Greenhouse Gas Programme lists a half-dozen "integrated systems demonstration projects" and almost 20 storage demonstration projects, but some have encountered difficulties and others are quite small in size (IEA GHG, 2007).

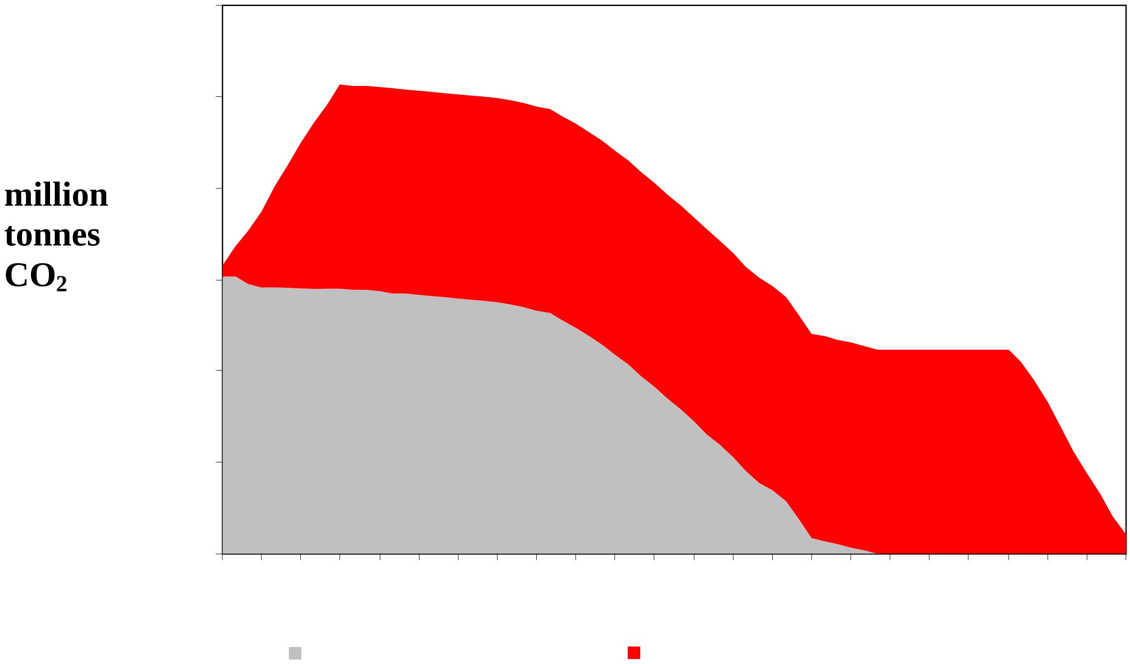


Figure 1 CO2 Emissions from Coal-Fired Power Stations built prior to 2015 in China & India (IEA, 2007)

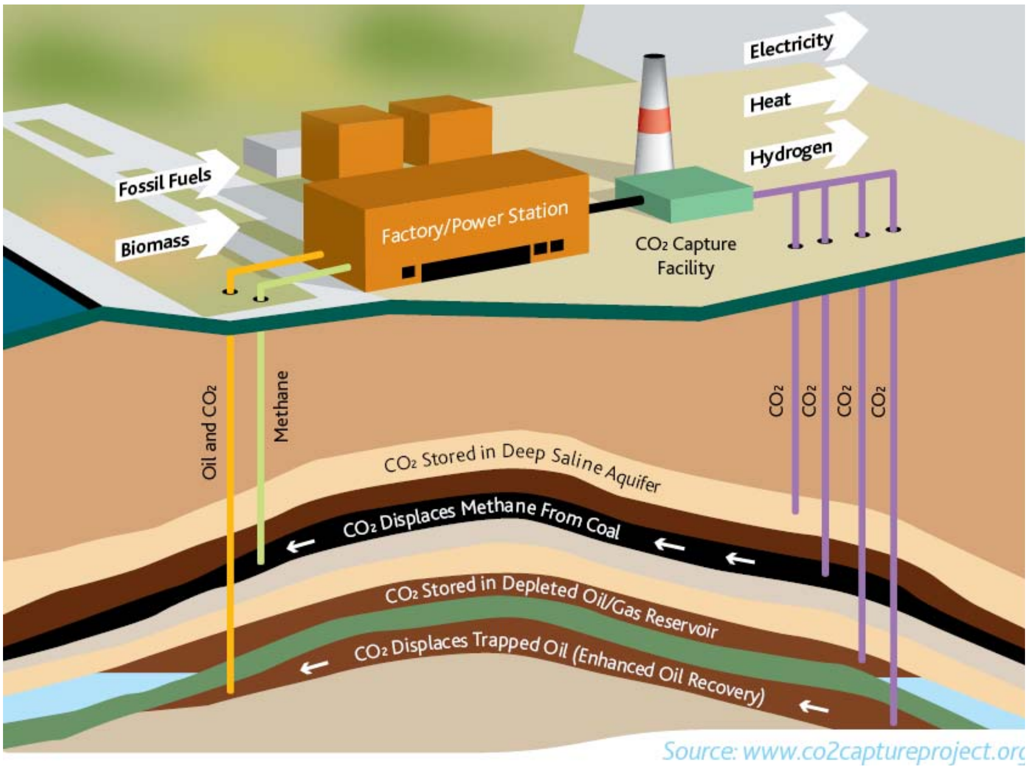


Figure 2 Schematic Diagram of a CCS system

Source: http://www.co2captureproject.org/technologies/tech_index.htm

Given the high costs (Table 1) and uncertainties over the technology (Table 2), currently, there is insufficient incentive to deploy CCS on a large scale before 2015 in most countries. In the long term, if deep cuts in carbon dioxide emissions become necessary, carbon prices may rise to levels that will make CCS economic (Venkataraman and Lundberg, 2007).

CCS system components	Cost range	Remarks
Capture from a coal- or gas-fired power plant	15-75 US$/t$CO_2$ net captured	Net costs of captured CO_2, compared to the same plant without capture.
Capture from hydrogen and ammonia production or gas processing	5-55 US$/t$CO_2$ net captured	Applies to high-purity sources requiring simple drying and compression.
Capture from other industrial sources	25-115 US$/t$CO_2$ net captured	Range reflects use of a number of different technologies and fuels.
Transportation	1-8 US$/t$CO_2$ transported	Per 250 km pipeline or shipping for mass flow rates of 5 (high end) to 40 (low end) MtCO_2 yr^{-1}.
Geological storage[a]	0.5-8 US$/t$CO_2$ net injected	Excluding potential revenues from EOR or ECBM.
Geological storage: monitoring and verification	0.1-0.3 US$/t$CO_2$ injected	This covers pre-injection, injection, and post-injection monitoring, and depends on the regulatory requirements.
Ocean storage	5-30 US$/t$CO_2$ net injected	Including offshore transportation of 100-500 km, excluding monitoring and verification.
Mineral carbonation	50-100 US$/t$CO_2$ net mineralized	Range for the best case studied. Includes additional energy use for carbonation.

[a] Over the long term, there may be additional costs for remediation and liabilities.

Table 1 2002 Cost Ranges for components of CCS systems. (IPCC, 2007: 43, Table TS.9)

CCS component	CCS technology	Research phase [a]	Demonstration phase [b]	Economically feasible under specific conditions [c]	Mature market [d]
Capture	Post-combustion			X	
	Pre-combustion			X	
	Oxyfuel combustion		X		
	Industrial separation (natural gas processing, ammonia production)				X
Transportation	Pipeline				X
	Shipping			X	
Geological storage	Enhanced Oil Recovery (EOR)				X[e]
	Gas or oil fields			X	
	Saline formations			X	
	Enhanced Coal Bed Methane recovery (ECBM)[f]		X		
Ocean storage	Direct injection (dissolution type)	X			
	Direct injection (lake type)	X			
Mineral carbonation	Natural silicate minerals	X			
	Waste materials		X		
Industrial uses of CO_2					X

[a] Research phase means that the basic science is understood, but the technology is currently in the stage of conceptual design or testing at the laboratory or bench scale, and has not been demonstrated in a pilot plant.
[b] Demonstration phase means that the technology has been built and operated at the scale of a pilot plant, but further development is required before the technology is required before the technology is ready for the design and construction of a full-scale system.
[c] Economically feasible under specific conditions means that the technology is well understood and used in selected commercial applications, for instance if there is a favourable tax regime or a niche market, or processing on in the order of 0.1 MtCO_2 yr^{-1}, with few (less than 5) replications of the technology.
[d] Mature market means that the technology is now in operation with multiple replications of the technology worldwide.
[e] CO_2 injection for EOR is a mature market technology, but when used for CO_2 storage, it is only economically feasible under specific conditions.
[f] ECBM is the use of CO_2 to enhance the recovery of the methane present in unminable coal beds through the preferential adsorption of CO_2 on coal. Unminable coal beds are unlikely to ever be mined, because they are too deep or too thin. If subsequently mined, the stored CO_2 would be released.

Table 2 Maturity of CCS Components
An ‘X’ indicates the component is considered mature (IPCC, 2006: 21, Table TS.1)

1.2 Getting Ready for Carbon Dioxide Capture & Storage

Making new fossil fuel plants Capture Ready would enable them to retrofit to capture CO_2 during their lifetime more easily and economically. The extra cost to retrofit a Capture un-Ready plant over the long-term compared with a hypothetical Capture Ready design is demonstrated in Table 3.

Supercritical PC (86% Net Emissions Reduction)		Capture un-ready	Capture ready
Original Efficiency	%LHV	42	42
Efficiency Penalty	%LHV	9.5	8.5
Capture plant capital cost (above original)	%	45.8	24.6
Estimated additional O&M cost	%	70	43

Table 3 Relative Benefits of Capture Ready (Gibbins, Li, and Liang 2006)

Following the G8 Gleneagles Plan of Action (G8, 2005), the IEA was asked to investigate the definition of Capture Ready that would avoid Capture "lock-in" and lower retrofit costs. The UK Energy Review published in April 2006 also indicated the importance of exploring Capture Ready technologies (DTI, 2006).

At the UK-China Cleaner Energy Technology and Policy Workshop in Xiamen China, Otter (2006) suggested that Capture Ready plants could be employed in the near- to mid-term (around 2012) as a transitional pathway towards the long-term goal of zero emissions (Figure 3).

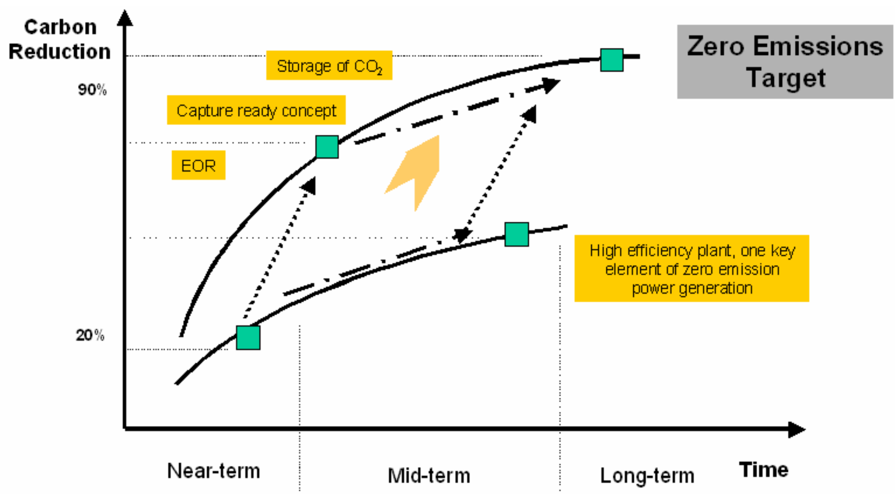


Figure 3 Pathway to Zero Emissions Power for Fossil Fuels (Otter, 2006)

A number of companies are considering making their plants Capture Ready. Table 4 below shows examples of industry efforts to plan for new plants to be Capture Ready since, to date, there have been no government mandates. Two UK projects related to making power plants Capture Ready were proposed shortly after HM Treasury emphasized the importance of Capture Ready (HM Treasury 2006). In Canada, SaskPower is working on the feasibility study to compare the economics of capture plants with renewables. And the proposed SASOL Coal to Liquid (CTL) project is proposing a design with Capture Ready in China, even though China has no obligation to reduce CO_2 emissions under the Kyoto Protocol.

Data	**Company**	**Activity**
2006.6	Scottish and Southern Energy (SSE) & Mitsui (now Doosan) Babcock	Retrofit SSE's 500 MW Ferrybridge Power Station in Yorkshire by installing Mitsui Babcock's supercritical boiler and turbine unit onsite to facilitate the subsequent development of post-combustion technology for carbon capture and storage (SSE 2006).
2006.10	E.ON-UK	A proposal to build two new 800 MW coal-fired power plants with Capture Ready in Kent. If successful, the plant could be operational by 2012 (Platts 2006)
2006	SASOL	Study the feasibility of building two 80,000 barrels per day (bpd) CTL plants in China, with Capture Ready (SASOL 2006).
2006	RWE-UK	Feasibility study of two 800 MW post-combustion Capture Ready plant in Tilbury. A future plan for a 3x800 MW Capture Ready plant in Blyth. (RWE, 2006)

Table 4 Industry Proposals for Capture Ready Design

2. Defining Capture Ready

2.1 Alternative Definitions of Capture Ready

Since 2000, General Electric (GE) has conducted many studies on coal-fired Integrated Gasification Combined Cycle (IGCC) power plants to obtain 'CO_2 sequestration ready' design (GE-EER, 2000). Their studies mainly focused on adopting pre-combustion capture technology to capture carbon dioxide, while at the same time producing high concentration hydrogen. In this case, Capture Ready means that the entire module for capturing CO_2 is built onsite during plant construction.

Gibbins (2004) suggested Capture Ready as being "Plant designed to have CO_2 capture added at some time in the future with minimal impact of lifetime economic performance." Aside from technical design, a critical element in any Capture Ready proposal is the need for the physical space to accommodate the additional plant needed.

The idea has also become popular among some environmental groups. In December 2004, the US environmental group Natural Resources Defense Council (NRDC)'s China Clean Energy Project listed 'promoting the development of Capture Ready in China for coal gasification based poly-generation (co-production of electricity and chemicals) as one of their national initiatives (NRDC, 2004).

Wilson and Gibbins (2005) raised a broader concept of 'Capture Ready' in early 2005. Their suggestions for Capture Ready include:

"a) Making sure that new fossil fuel plants of all types are built so that, within the limits of the best current understanding, they can have capture retrofitted in the future with the minimum additional cost and performance penalty.

b) Improving the technologies that will be needed to convert these 'capture ready' plants (and other existing plants) to capture CO_2, and feeding experience from this back into capture ready plant design.

c) Making sure that any additional technologies that may not be so competitive until CO_2 capture becomes the norm are also developed for rapid deployment when they will be needed.

d) Developing proven and socially acceptable CO_2 storage options. "

Rosenberg et al (2005) suggested legislative language in the US context that Capture Ready design for IGCC plant: 'be capable of accommodating the equipment likely to be necessary to capture the carbon dioxide that would otherwise be emitted in flue gas from the project'. Although Rosenberg et al mentioned a plant should be capable of being retrofitted into a capture plant for its sustainable use, it does not require any technology investigation to support that the plant is built for a cheaper retrofit. Moreover, Capture Ready should not be restricted to IGCC plants but applied to conventional Pulverized Coal (PC) plants as well.

Capture Ready should not be restricted to 'Capture' alone in the sense that a CCS project will need to be integrated across Capture, Transport and Storage. Accordingly, the concept of

Capture Ready should ideally incorporate plant siting to allow as much as possible of the captured CO_2 to be transported to the storage site in order to lower the total cost of the whole CCS process.

In March 2006, in a paper published by HM Treasury, Capture Ready was given a broad and simple explanation, and it spelled out the key issue for a capture ready plant, i.e., it should be less expensive to retrofit the plant (HM Treasury, 2006: 4).

Bohm et al define Capture Ready to mean: ‘if, at some point in the future [the plant] can be retrofitted for carbon capture and sequestration and still be economical to operate.’ Moreover, they conThe concept of ‘capture-ready’ is not a specific plant design; rather it is a spectrum of investments and design decisions that a plant owner might undertake during the design and construction of the plant. (Bohm, Herzog, Parsons and Sekar, 2007: 114)

In February 2007, Scott Brockett from DG Environment within the European Commission, suggested all new coal-fired power generation plants prior to 2020 must be Capture-Ready and retrofit rapidly after 2020 (Brockett, 2007a). In July 2007, a Capture Ready study by the Institution of Chemical Engineers (IChemE) warned that ‘lack of clear definition will hamper a low carbon economy’ (IChemE, 2007). However, the European Commission has chosen not to give detailed definition of Capture Ready requirements. Intending to require capture on all coal plants after 2020, Commission officials possibly have taken the view that firms will be penalized at a later date for any corners cut and so there is no need for any explicit definition similar to ‘the Broad Sense Capture Ready’ definition given in Section 2.2 (Brockett 2007b).

2.2 Broad Sense Capture Ready and Narrow Sense Capture Ready

Liang (2006) summarized and classified existing Capture Ready explanations and definitions into ‘Broad Sense’ and ‘Narrow Sense’ categories. As its name implies, supporters of a ‘Broad Sense’ Capture Ready believe that any design or investment that can ease retrofitting a plant with carbon dioxide capture and storage in the future can be called Capture Ready, while the proponents of ‘Narrow Sense’ Capture Ready insist that a plant must be in compliance with specific technical requirements to claim Capture Ready status.

Under this classification system, the GE and NRDC definitions would be considered Narrow Sense Capture Ready, and the HM Treasury, Gibbins and Bohm et al explanations fall under the Broad Sense definition of Capture Ready. Generally, the Broad Sense definition of Capture Ready is better than the Narrow Sense definition for expansion investments, whereas when Capture Ready is mandatory, the Narrow Sense definition is preferred. Companies from industry in developed countries have started to become aware of the value of making new fossil fuel plants Capture Ready based on the broad sense definition. Some power companies are planning to invest using internal financial resources (NRDC, 2004).

How can new plants be encouraged to become Capture Ready? An obvious way to stimulate Capture Ready would be to develop and announce a clear timetable for imposing CCS regulations, because it would help power companies judge what the optimal investment would be by assessing the risks or opportunities of mandatory CCS in the future. However, this kind of regulatory signal on CCS has not yet been occurred in major industrialized countries let alone in developing countries. A major potential hurdle of facilitating new plants is information inefficiency, partly due to inconsistent interests and different decision-making criteria used by power companies and regulators.

3. Prospects for Financing Capture Ready in Developing Countries

3.1 Current Obstacles to Financing Capture Ready

Capture Ready does not reduce emissions directly, and therefore it is not eligible to be financed through either the EU Emissions Trading Scheme (ETS) or the Clean Development Mechanism (CDM) available to developing countries. Unlike developed countries, where there is a credible possibility that governments will mandate CCS on all new coal plants in the near future, developing countries such as China will need to rely on outside investors to encourage Capture Ready, at least in the short term.

Furthermore, China is building more new coal-fired power capacity than anywhere else in the world. However, the current prospects for financing Capture Ready in China are not promising. Reiner et al (2007) conducted a survey of more than 100 key opinion leaders on CCS in China. Capture Ready, described as a pre-investment option to ease retrofitting to Capture in the future, was recognized as an option by a majority of respondents, but about half of respondents suggested that the Chinese government should not intervene in the

Capture Ready decisions of individual projects. Industry, especially the electric power industry, was also found to be risk averse with respect to Capture Ready investment. As a result, the chance of incentivising Capture Ready through existing channels, whether through the Chinese government, industry or the CDM is low in the near term.

3.2 An Innovative Approach to Finance Capture Ready

Capture Ready is crucial, but attracting conventional financing sources is not currently viable. In order to finance newly built fossil fuel power plants to become Capture Ready, we introduce the concept of a tradable Capture Option and provide estimates of its value.

Section 4 introduces the principles and benefits of Capture Options. By employing Monte Carlo simulations with a randomized cash flow model, Section 5 evaluates the net present value (NPV) for both Capture Options and Capture Ready investments for the case of a 600 MW supercritical FGD unit. In the following sections we seek to answer the following research questions:

- How can a Capture Option help finance Capture Ready?
- What is the potential benefit of Capture Ready?
- What is the value of a Capture Option?

4. Benefits and Challenges of Trading Capture Options

4.1 Definition of a Capture Option

A Capture Option is an option contract which stipulates that one party (the holder) has the right (but not the obligation) to exercise the contract to require the capture of CO_2 on or before a future date (the exercise date or expiration) and the other party is a stationary CO_2 emitter such as a power plant owner. A perfect Capture Option is an American-style option, which allows the option holder to exercise their option to capture CO_2 at any time before expiration. If the prospect of CO_2-enhanced oil recovery (EOR) is not available, the underlying asset is the carbon credit price, while the strike price is the floating opportunity cost of retrofitting to Capture, which primarily depends on the costs and risks of capture technologies, fuel cost, and the prices of, and demand for, products (e.g. electricity, cement). in the base plant. If EOR prospects do exist, then the oil price will also be an underlying asset .

4.2 Potential Market in Capture Options

Capture Options will be issued by new or existed stationary CO_2 sources, including fossil fuel power plants, and a range of other industries where capturing CO_2 would be viable including cement, fertilisers, iron and steel, and petrochemicals. By purchasing capture options, the option holders will be able to exercise the options, Capture CO_2 and then inject it into underground thereby generating carbon credit and/or returns from EOR whenever economic. CCS operating companies, oil companies and power companies may therefore have a relatively high synergy in deciding to exercise Capture Options.

4.3 Opportunities to Profit from Capture Options

How can investors in Capture Options make a profit? If option holders decide to exercise the option - which means retrofitting the other party's plant to capture CO_2, their potential benefit is the net cash flow generated by CO_2 emissions reductions or other CO_2 utilization opportunities such as Enhanced Oil Recovery (EOR). Similar to other financial options, an option holder is also able to make a profit by selling options to other investors before the expiry date of the option.

4.4 Financing and Optimizing Capture Ready

By selling Capture Options, the shareholders of fossil fuel plant get extra cash inflow immediately, and part of the money may be spent to achieve some level of Capture Ready. *To optimize the economic benefits, shareholders in fossil fuel plants will continue to invest in Capture Ready if the marginal price of the Capture Option is higher than the marginal cost of Capture Ready investments* (Capture Ready here is based on the Board Sense definition of Capture Ready, as described in Section 2.2, 'any design or investment that can ease retrofitting a plant with Carbon Capture and Storage in future can be called Capture Ready').

4.5 Other Benefits of Issuing a Capture Option

CCS Investment Opportunities in Focus

For investors, the demand for global warming investment products is growing rapidly (Clarke, 2006). Capture Options create an alternative global warming investment opportunity, which, for the first time, allows investors to acquire returns from the development of CCS without directly investing in the power generation or oil industry. It helps to introduce more investors into the world of CCS by developing a financial instrument with broader appeal.

Accelerating CCS Development

Once institutional investors hold large quantities of Capture Options, they may tend to increase the value of their holding immediately by engaging in political activities such as promoting methodologies to introduce CCS into the CDM or advising policymakers to reduce regulatory hurdles to CCS. Alternatively, technology development will increase the price of a Capture Option by reducing an option's exercise price, which is the cost of retrofitting a plant to capture CO_2.

Secure Emissions Reduction Target

A government or its agencies can purchase and deposit a large number of Capture Options at relatively low cost to secure their long-term emissions reduction target or commitment. For instance, if the British government had purchased Capture Options for new coal fired plants built in China in 2005 and 2006, then the UK would easily achieve even the most ambitious emissions reduction targets by exercising a fraction of their options. Emissions reductions generated from capturing CO_2 at all new coal-fired plants built in 2005 and 2006 in China would be more than twice the emissions from the entire power sector in the UK.

Facilitating EOR (Enhanced Oil Recovery) in Future

Demand-side investors such as oil companies are potential holders of capture options, because purchasing Capture Options enables them to secure their future CO_2 supplies for potential EOR projects in advance. Furthermore, the opportunity cost of investing in Capture un-Ready plant because of inefficient information dissemination between fossil plants and oil companies, and the time lag between plant constructions and using the CO_2 in EOR, can be recovered and reflected in the value of Capture Option.

Managing the Risks of Capture Ready Investments

From a risk management point of view, investment in Capture Ready may be exposed to higher risk of 'Capture Lock-in' in the absence of an active market of tradable Capture Options. For example, if a local government instituted a ban on CCS because of concerns over pipeline leakage in a high population density area, a plant would not be able to use CCS even though carbon prices might be high enough to make it profitable. However, if there is an active capture options market, the risk and benefits of Capture Ready investment will be easier to quantify or transfer. By trading Capture Options, plant shareholders can manage their non-systematic risk more efficiently. For example, in theory, investors in fossil fuel plants could sell part of the Capture Option of their home plant and purchase Capture Options from other plants located in different regions or investors who have different risk perceptions could diversify the non-systematic risk of ‘Capture lock-in’.

Capture Ready - No longer a cost

As described in greater detail in Section 5, Capture Options not only increase the value of a project significantly but also reduces the risk from carbon prices for a new coal-fired unit - measured in terms of the standard deviation (Std dev). The analysis in Section 5 also shows that a Capture Option for a 600 MW supercritical FGD unit in China would be worth over one hundred million Chinese yuan ($14m) using a 8% discount rate in two of four scenarios thereby increasing the project’s initial cash flow.

Finally, the most important benefit of a Capture Option is to make shareholders of fossil fuel plants become more aware of the real options value of capturing CO_2 and to optimize the options’ value by investing in some level of Capture Ready based on the broad sense definition. In other words, the option to capture CO_2 would come to be regarded as an ‘asset’ rather than a ‘liability’, and in the meantime while a Capture Ready investment may lift the value of a project.

4.5 Potential Hurdles of Issuing Capture Options

Liquidity Risks and Possible Solutions

Only one capture option would be available for each generation unit, and the economic prospects of Capture are not identical among generation units, thus it is difficult to generate a liquid exchange trading market for capture options trading directly. Capture options would be suitable for over-the-counter (OTC) trading, which involves trading between two parties. However, we suggest creating professionally-run capture option funds managed by CCS and financial experts. Such funds would allow for options to be traded liquidly on an exchange and can increase bargaining power, the efficiency of option pricing and decisions regarding retrofitting.

Regulatory Hurdles

In some countries, including China, issuing and trading Capture Options will be subject to the permission or authorization of national governments, adding some additional uncertainties. Uncertainties in approving CCS projects may therefore reduce the value of a Capture Option. The multiple uncertainties characteristic of Capture Options may lead to difficulties in pricing.

Maintaining Capture Ready Infrastructure

The owners of power plants may be reluctant to maintain Capture Ready infrastructure after issuing Capture Options because they are not likely to benefit from exercising the options by retrofitting to Capture. One solution is to require that Capture Ready settings in place at the time of issuing the Capture Option be maintained either through regulation or via contract. On the other hand, the willingness to maintain Capture Ready may be enhanced if the original plant owners keep a proportion of the Capture Options.

Asymmetric Information

Plant owners will know earlier and more about the status of their plants, which influences the option price and would give them an advantage over other investors. Setting up an independent accreditation body and regulating the trading activities of those who hold non-public information may help reduce the danger of insider trading.

5. Pricing Capture Options: Building the Model Applied to a Case Study

5.1 Methodology

Valuing Capture Options

For the purposes of this analysis, we assume mean net present value (NPV) of total cash flow as the main investment decision criteria. NPV is the net present value of the future after-tax cash flows after subtracting initial investment outlay and adding present value of terminal year non-operating cash flow, or

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - Outlay + \frac{TNOCF}{(1+r)^n} \qquad (2\text{-}1)$$

Where

CF_t = after-tax cash flow at year t

r = required rate of return for the investment (or discount rate)

Outlay = investment cash flow at time zero

n = life of the power project

TNOCF = terminal year after-tax non-operating cash flow

We project the value of a Capture Option by subtracting the 'mean NPV of total cash flow of a project without the option of retrofitting to Capture during its lifetime' from 'mean NPV of total cash flow of a project with the option of retrofitting to Capture':

$$Value_{Option} = \overline{NPV_{with-option}} - \overline{NPV_{without-option}} \qquad (2\text{-}2)$$

where

$NPV_{with\text{-}option}$ = net present value of total cash flow with retrofitting option

$NPV_{without\text{-}option}$ = net preset value of total cash flow without retrofitting option

In order to estimate the mean NPV of total cash flow including options for retrofitting to Capture, a decision equation with regard to retrofit timing is required. The model assumes that plant owners or Capture Option holders will retrofit the plant to capture CO_2 at year T when the projected average NPV of total future cash flow with retrofitting is larger than the projected average NPV of future cash flow without retrofitting:

$$\text{Retrofitting to Capture if } \overline{\sum_{t=T}^{n} \frac{CF_{retro\_t}}{(1+r)^{t-T}}} > \overline{\sum_{t=T}^{n} \frac{CF_{no-retro\_t}}{(1+r)^{t-T}}} + Value'_{option} \qquad (2\text{-}3)$$

where

CF_{retro_t} = after-tax randomized cash flow at year t with retrofitting to Capture

$CF_{no\text{-}retro\_t}$ = after-tax randomized cash flow at year t without retrofitting to Capture

$Value'_{option}$ = the option value of retrofitting to Capture in the future

T = retrofitting year

n = life of the power project

Benefits of Capture Ready

The additional capital outlay needed to make a new plant Capture Ready will depend upon the siting of the plant, engineering design and local costs of reserving additional land, thus we focus on the gross value (before capital outlay) of Capture Ready:

$$GValue_{cr} = Value_{option-cr} - Value_{option-nocr} \qquad (2\text{-}4)$$

where

$GValue_{cr}$ = value of Capture Ready before capital outlay of Capture Ready

$Value_{option\text{-}nocr}$ = value of Capture Option without Capture Ready

$Value_{option\text{-}cr}$ = value of Capture Option with Capture Ready

A distinct advantage of building new plants with Capture Ready is increasing the cumulative probability of retrofitting to Carbon Capture economically over the course of a plant's lifetime:

$$P_{capture-T} = 1 - P_{unCapture-T} = 1 - \prod_{t=1}^{T} (1 - p_{capture-t}) \qquad (2\text{-}5)$$

$$p_{capture-T} = p(\overline{\sum_{t=T}^{n} \frac{CF_{retro\_t}}{(1+r)^{t-T}}} > \overline{\sum_{t=T}^{n} \frac{CF_{no-retro\_t}}{(1+r)^{t-T}}}) \qquad (2\text{-}6)$$

where

$P_{capture\text{-}T}$ = cumulative probability of retrofitting to Capture at Year T

$P_{uncapture\text{-}T}$ = cumulative probability of not yet retrofitting to Capture at Year T

$p_{capture\text{-}T}$ = probability of retrofitting to Capture at Year T

The net value of Capture Ready is equal to the 'gross value of Capture Ready' less 'additional capital outlay on Capture Ready':

$$Value_{cr} = GValue_{cr} - Outlay_{cr} \qquad (2\text{-}7)$$

where

$Value_{cr}$ = Net Value of Capture Ready (after capital outlay)

$GValue_{cr}$ = Gross Value of Capture Ready (before capital outlay)

$Outlay_{cr}$ = Capital Outlay on Capture Ready

A proper Capture Ready design should have little impact on operating performance and the capital required for Capture Ready investment is much smaller than the outlay for the baseline PC plant. Therefore, we ignore the operating risk after Capture Ready investment and assume the Capture Ready investment decision will not affect the required return of capital.

Cash Flow Components

The underlying power project in the study is a new investment, thus the initial capital outlay is equal to investment in new fixed capital plus investment in net working capital.

$$Outlay = FCInv + NWCInv \qquad (2\text{-}8)$$

where

$FCInv$ = Investment in new fixed capital

$NWCInv$ = Investment in net working capital

The annual after-tax operating cash flow is equal to 'revenue (or sales) less cash operating expenses and tax expense, plus depreciation charge':

$$CF_t = (S_t - C_t - D_t)(1 - Tax) + D_t \qquad (2\text{-}9)$$

where

S_t = revenue from electricity sales at year t

C_t = cash operating expenses (fuel cost + carbon cost + other O&M costs) at year t

D_t = depreciation charge at year t

Tax = corporate tax rate

We assume the salvage value is zero at the end of the project. Therefore the terminal year non-operating cash flow is equal to:

$$TNOCF = NWCInv + Tax \times B_{TN} \qquad (2\text{-}10)$$

where

$TNOCF$ = terminal year after-tax non-operating cash flow

B_{TN} = book value of fixed capital on the terminal date

Options of Terminating ahead of Schedule

If the prospect of continuous operation (with a retrofit option or after retrofitting to Capture) is extremely unfavourable, the underlying plant will be closed down ahead of its designed life. We assume that the plant will be terminated if the spot NPV of future cash flows with closure options is lower than zero.

5.2 Assumptions

In order to run 'near-realistic' scenarios, we make a series of assumptions based on historical data and adjusted for potential inflation and growth, including technical performance without capture of CO_2, the technical performance with capture of CO_2, financial environment and market forecasts. The assumptions are summarized in Table 5.

Technical Performance Assumptions without Capture					
Unit Type	Supercritical Pulverized Coal				
Installed Capacity	600 MW				
Start-Construction Timing	1st Jan 2010				
Construction Cycle	24 months (low scenario); 36 months (high scenario)				
Operating Life	2012-2050				
Average Capacity Load	Period	%		Period	%
	2012-2020	80%-90%		2031-2040	70%-80%
	2021-2030	75%-85%		2041-2050	65%-75%
Power Supply Efficiency	42%				
Emissions Factors	0.79 ton CO_2/MWh				
Capital Outlay	CNY3750/kW (2003 base) plus extra 5% working capital				
O&M cost	CNY134.4m (2006 base)				
Technical Performance Assumptions with Capture					
Additional Capital Outlay*	Without Capture Ready	45.8% above original			
*with 5% working capital	With Capture Ready	24.6% above original			
Efficiency Penalty	Without Capture Ready	9.5%			
	With Capture Ready	8.5%			
Additional O&M Cost	Without Capture Ready	70% above without Capture			
	With Capture Ready	43% above without Capture			
Average Capacity Load	Period	%		Period	%
	2012-2020	85-95%		2031-2040	80%-90%
	2021-2030	75%-85%		2041-2050	70%-80%
Possible Retrofitting Year	2017, 2022, 2027, 2032, 2037, 2042, 2047				
Transport, Storage, and Monitoring costs	CNY 0.6 (low) to CNY 16.3 (high) per metric ton CO_2				
Financial Environment					
Corporate Tax Rate	25%				
Depreciation Schedule	10-year straight line				
Required Return (not fixed)	6%, 8%, 10%, 12%				
Market Assumptions					
Inflation	Basic	1.5 (Low), 4.5%(High)			
	O&M	1.5 times of basic inflation			
	Fixed Capital	3.4%			
Coal Prices	Base	CNY338 (2006)			
	Std dev	10%			
	Annual Growth	= basic inflation			
Carbon Prices	Base	CNY80/ton (2006)			
	Std dev	20% (pre-2020), 10% (post- 2020)			
	Annual Growth	4.5% (low); 8% (high)			
Electricity Prices	Base	CNY349.1/MWh (2006)			
	Std dev	2.5%			
	Annual Growth	= basic inflation			
Correlation (coal, carbon)	-10% (low), -60% (high)				
Correlation (electricity, coal)	20% (low), 80% (high)				

Table 5 Model Assumptions Summary

Technical Performance Assumptions without Capture

In January 2007, the National Development and Reform Commission (NDRC) announced the closure of a total of 50 GW of small coal-fired generation units by 2010 in order to reduce coal consumption and local air pollution (NDRC, 2007). Meanwhile, NDRC (2007) indicated that new-built coal-fired power plants should at least have the capacity and the thermal efficiency equivalent to a 600 MW supercritical plant or an ultrasupercritical unit if at all possible. Therefore, 600 MW or larger supercritical coal-fired units seem likely to become dominant in China in the short term.

Due to multiple uncertainties, we apply a cash flow model with Monte Carlo (MC) simulations to conduct a scenario analysis of the value of a 600 MW supercritical coal-fired project, which is assumed to begin construction in 2010 in China. The simulation applies 10,000 trials as it achieved a standard error of less than 1% consistently. The technical and operating assumptions are based on Huaneng's 600 MW supercritical units finished construction between 2004 and 2006 and then adjusted as appropriate. Huaneng Power International Corporation, a subsidiary of China Huaneng Group, is one of the leading independent power companies in China, with shares actively traded in Hong Kong, Shanghai, and New York (as ADR).

The construction cycle of 600 MW supercritical units built by China Huaneng Group (CHNG) and finished in 2006 varied from 24 to 35 months (CHNG, 2007). Accordingly, we assume the construction cycle is from 2 to 3 years in 2010. The average equivalent availability factor (EAF) of plants in the Huaneng Group is above 90% (CHNG, 2007). Considering the technical performance of the 600 MW supercritical units and the impact of an energy-efficiency policy which allocates more generation quotas to higher efficiency units, we assume that the capacity load for a new supercritical unit constructed in 2010 would decrease from 85% to 70% over its 40 year lifetime (Table 6).

Time period	2012-2020	2021-2030	2031-2040	2041-2050
Load Factor	80%-90%	75-85%	70-80%	65%-75%
Output/yr (MWh)	4,467,600	4,204,800	3,942,000	3,679,200

Table 6 Projected Average Capacity and Load Distribution of a 600 MW supercritical unit

The power supply efficiencies of existing 600 MW supercritical units operated by Huaneng Group are between 41% and 43% (LHV). To simplify calculations, we assume the power supply efficiency of the underlying plant is 42%, consistent with the efficiency assumptions for the SC-PC plant scenario in Table 3.

The historical initial capital investment for 2x600 MW SC-PC units in different regions of China was similar, varying between CNY4.4 billion and CNY4.6 billion at 2003 prices (CHNG, 2007; CPNN, 2007). Thus, we employ CNY2.25b ($300m) as the reference capital needed for a single 600MW supercritical unit in 2003 (excluding any provision for inflation), which is equivalent to CNY3750/kW ($500/kW) and we assume the working capital is 5% of total capital investment, which is CNY187.5/kW ($25/kW). To simplify the calculations, the total investment outlay after inflation adjustment is equally distributed across the first two construction years in the model. By linear approximation, Operating & Maintenance (O&M) cost (including labour cost, maintenance cost, environment, insurance and other administration costs) was estimated to be CNY134.4m for a 600 MW SC-PC unit in 2006 (Huaneng Intl. Inc., 2007).

Regarding the emissions factor, Rubin et al. (2005, quoted in IPCC 2006: 151) estimated a 524 MW net output supercritical unit at 40.9% generation efficiency would emit 0.811 ton CO_2/MWh without Capture, based on a 2.1% Sulphur bituminous coal. By linear approximation, assuming the same coal input, the carbon emissions factor of the underlying plant (42% efficiency, 600MW) in the model would be 0.79 ton CO_2/MWh without Capture.

The technical performance assumptions for a Capture Ready plant can be found in Table 3.

Technical Performance with Capture

As seen in Table 3, a plant that is not Capture Ready would require a premium of 75% above the original investment cost (versus 50% for a Capture Ready plant) and an additional year's construction time to retrofit to Capture. Gibbins (2005) estimated that the efficiency penalty would be 9.5%, while O&M costs would be increased by 70%.

The average capacity load factor after retrofitting to Capture is assumed to rise by 5% to recover part of the net output loss (Table 7).

Time period	2012-2020	2021-2030	2031-2040	2041-2050
Average Capacity Load	85%-95%	80%-90%	75%-85%	70%-80%
Output/yr (MWh)	3,660,429	3,457,071	3,253,714	3,050,357
Coal/yr (ton)	1,384,115	1,307,220	1,230,324	1,153,429

Table 7 Projected Average Capacity Load Distribution of a 600 MW Supercritical Unit after Retrofitting to Capture

Gibbins (2005) predicted that in a supercritical-FGD plant built with a specific Capture Ready, the retrofitting cost could be reduced to 50% above the original cost while the efficiency penalty would be reduced by 8.5%, and O&M cost would be increased by 43%, as stated in Table 3. The value of the Capture Option with Capture Ready is presented before deducting additional capital outlays for Capture Ready.

In our model, retrofit timing takes advantage of the scheduled routine maintenance cycle (which normally takes four months). Therefore, the decision nodes on whether to retrofit is set at routine maintenance years which will be every five years starting from 2017 (Table 8).

No.	1st	2nd	3rd	4th	5th	6th	7th
Year	2017	2022	2027	2032	2037	2042	2047

Table 8 Projected Routine Maintenance Schedule of the Underlying 600 MW SC-PC (potential retrofitting year)

Expert costs estimations of storage, monitoring and transport in Europe, US and Australia were between \$0.3 to \$8.6/mtCO_2 (IPCC, 2006: 344). After adjustment for the implied purchasing power parity between China and major advanced economies, about 1 to 3.95 (IMF, 2007), we assume that the costs of storage, monitoring and transportation are CNY0.6 to CNY16.3 /mtCO_2 in 2006 respectively.

Financial Environment

In March 2007, the Tenth National People's Congress enacted the new Enterprise Income Tax Law ("New Law") which unified the income tax levied on domestic and foreign enterprises.

The law introduced a single tax rate of 25% and takes effect on 1 January 2008 (Deloitte, 2007). Therefore, for the supercritical unit in this model (starting operation in 2012) an income tax rate of 25% is assumed.

The depreciation schedule can have a significant impact on cash flow net present value. In reality, the depreciation schedule should be designed to optimize the economic benefit of plant investors after complying with tax regulations. In China, the State Administration of Taxation (SAT) mandates that fixed assets at manufacturing facilities are depreciated by a minimum 10 years straight line method (SAT, 2000).

Taxable earning in a consolidated statement of the parent company can be deducted by the un-deducted amount (if the project records a loss) of fuel cost, fixed O&M cost, carbon cost, and depreciation in the individual project's income statement. However, the tax shield effect may not be available when the parent company of the project records a continuously negative EBITDA (earning before interest, tax, depreciation and amortization) over five years. Knowing only information for an individual project, it is difficult to estimate the financial situation of the parent company. Such an extreme financial-situation (continuous losses) poses difficulties in estimating the amount of tax saving. Therefore, the model assumes the contribution of tax saving from losses in a power project will reduce accordingly when annual EBITDA is projected to be negative in the following four normal-operating years.

The discount rate has two components: the time value of money and the risk premium. We sought to develop a reference discount rate (required return) for Huaneng Power by using a weighted average cost of capital (WACC) method based on publicly available information from financial markets in Hong Kong (converted into Chinese Yuan). The capital asset pricing model (CAPM) approach found that over the past five years the cost of equity of Huaneng fluctuated between 14% and 16%, while the after-tax cost of debt was 4% to 6%. Using 1.25:1 as the debt to equity ratio over 2005-7 (Huaneng, 2007), the historical WACC-implied discount rate (required return) is between 7.5% and 9.5%. On the other hand, the risk of an individual project may be quite different from the risk posed to the project's parent company, which may have a well-diversified power investment portfolio, so it is difficult to determine a single incontestable discount rate. As a result, we conducted a sensitivity analysis for discount rates of 6%, 8%, 10%, and 12% rather than a single reference discount rate.

Market Assumptions

Using the historical time series of inflation in China through 2006 (IMF, 2007), the long term overall inflation rate is assumed to be 1.5% in the low scenario and 4.5% in the high scenario, whereas the inflation rate for O&M is assumed to be 1.5 times the basic inflation rate to reflect the rising costs of environmental protection and labour in China. The fixed-capital cost inflation is set at 3.4%, equivalent to the annual Chemical Engineering Plant Cost Index (CEPCI) from 1956 to 2005 (Brown, 2007). We also apply the long-term overall inflation rate to the costs of transport, storage, and monitoring.

Based on a review of various contract carbon prices for CDM projects in 2006, we assume the reference carbon prices for 2008 is CNY80/ton (€8/ton or $10.7/ton). The low and high annual growth scenarios are 4.5% and 8% respectively to reflect the increasing importance of mitigating climate change and a standard deviation of 20% is assumed to reflect the high volatility. Over time, we believe that the carbon price will be less volatile after the international regime has operated for a few years, thus, a 10% standard deviation for the carbon price is assumed post-2020.

The model uses Huaneng's average coal price, which was CNY338 per ton in 2006 (Huaneng, 2007), and assumes that the change in price is identical to the expected inflation rate (2.5%) in the long term. The model also assumes two correlation scenarios between coal prices and carbon prices: -10% (low) and -60% (high).

The adjusted average electricity price of Huaneng's coal-fired power plants in 2006 was CNY349.1/MWh (Huaneng, 2007). As the costs of meeting environmental standards and labour costs are expected to increase rapidly over the long term, the growth rate of the electricity price is taken to be identical to the assumed basic inflation rate. Compared with the carbon price or the coal price, electricity prices are relatively stable, so a 2.5% standard deviation is assumed to reflect the price volatility. Beginning in 2005, NDRC started a new power pricing mechanism linking electricity prices with coal prices, although the mechanism is not fully implemented. Therefore, given the important potential link between the two prices, we assume two correlation scenarios between electricity prices and coal prices, for which 64% of the volatility (R^2) of the electricity price can be explained by coal price fluctuations in the high scenario and 4% in the low scenario.

5.3 Results

The Value of the Capture Option

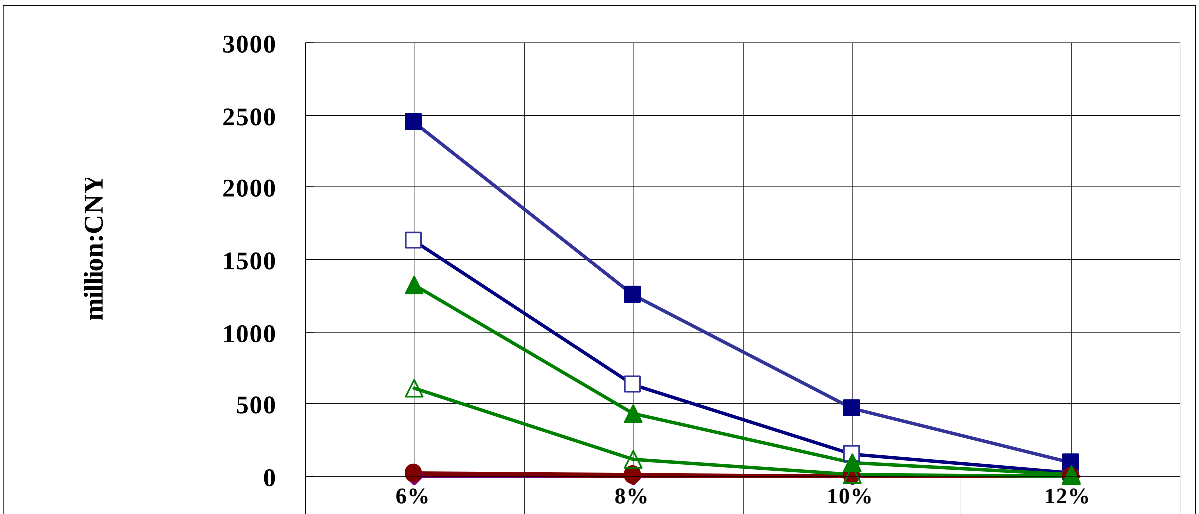
What is the theoretical value of the Capture Option? The value of a Capture Option varies from CNY 1m to 471m ($0.1m to $62.8m) at a 10% discount rate in 2010, depending on the scenario (Figure 4). The coding of scenarios is described in Appendix I and the assumptions of selected scenarios are also highlighted in Table 9.

The value of the capture option is sensitive to the input uncertainties. The Capture Option amounts to CNY609 million ($81.2m) at a 6% discount rate with Capture Ready investment in the LP scenario (when the construction cycle, the capacity load before the Capture, the Transport, Storage and Monitoring cost, basic inflation, the correlation between coal prices and carbon prices, the correlation between electricity prices and carbon prices are all at their lower bounds and the capacity load after Capture and the growth in carbon prices are at their upper bound) (Table 9). On the other hand, the option is valued close to zero at a 12% discount rate without Capture Ready investment in scenario LP. The impact of uncertainties on the Capture Option is described in Appendix I.

	Scenarios			
Uncertainties	**HO**	**LO**	**HP**	**LP**
Construction cycle	Low	High	Low	High
Capacity load before Capture	Low	High	High	Low
Capacity load after Capture	High	Low	High	Low
Transport, storage and monitoring costs	Low	High	Low	High
Inflation	Low	High	High	Low
Carbon price growth	High	Low	Low	High
Correlation (coal, carbon)	Low	High	High	Low
Correlation (Electricity, carbon)	Low	High	High	Low

HO: High Option Value; LO: Low Option Value; HP: High Project Value; LP: Low Project Value.

Table 9 Assumptions of Selected Scenarios



	6%	8%	10%	12%
Scenario HO_nCR	1625	627	153	22
Scenario HO_CR	2451	1255	471	97
Scenario LO_nCR	3	1	1	0
Scenario LO_CR	7	2	1	0
Scenario HP_nCR	10	2	2	0
Scenario HP_CR	25	7	5	2
Scenario LP_nCR	609	113	16	0
Scenario LP_CR	1326	439	99	11

nCR: without Capture Ready, CR: Capture Ready

Figure 4 Scenario Analysis of Capture Option Value

Besides revealing the value of a Capture Option, perhaps even more importantly, we found that the existence of a Carbon Capture Option may significantly raise the NPV of the underlying plant and reduce the standard deviation (std dev) of the project's NPV, which serves as a proxy for risk.

The potential impact of uncertainty on the project NPV is highlighted in Appendix I.

The Value of Capture Ready Investment

The pricing model reveals that the gross value of Capture Ready investment in the underlying plant are between CNY 3 million ($0.4m) and CNY 630 million ($84m) at a 8% discount rate. We also found that higher discount rates adversely affect the value of the Capture Option, as shown in Figure 5. For example, in scenario HO, the gross value of Capture Ready drops dramatically from 830m ($110.7m) at 6% discount rate to only CNY 71 million ($9.5m) at 12%. In other words, if Capture Ready investment requires CNY 200 million ($26.7m), in scenario HO, the investment will be highly profitable at 6% discount rate but uneconomic at a 12% discount rate.

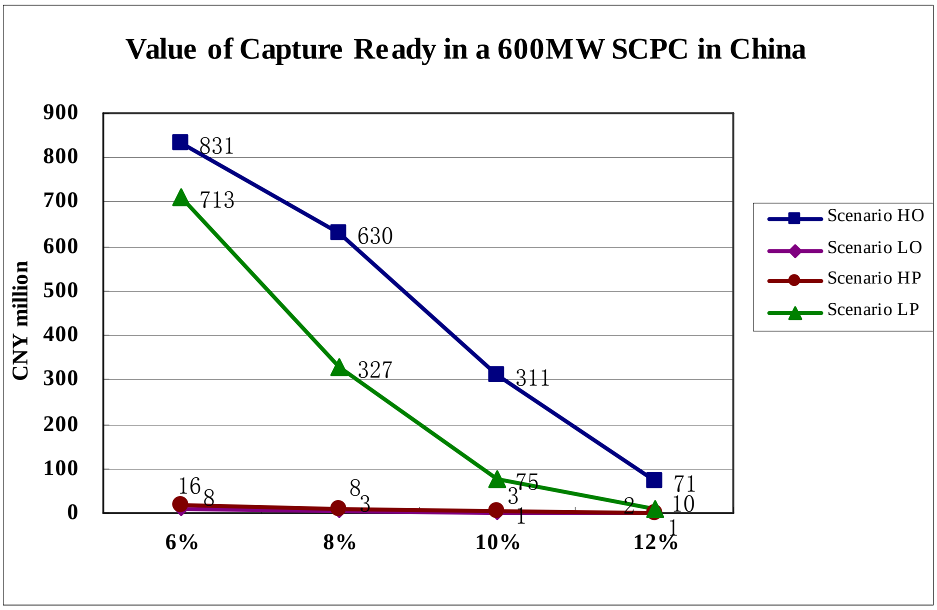


Figure 5 NPV for Capture Ready under Different Scenarios

Capture Ready investment may also increase the probability of retrofitting to Capture. As shown in Figure 7, the probability of Capture increases significantly from 34% to 80% using an 8% discount rate in scenario LP. On the other hand, the probability of retrofitting is adversely affected by the discount rate.

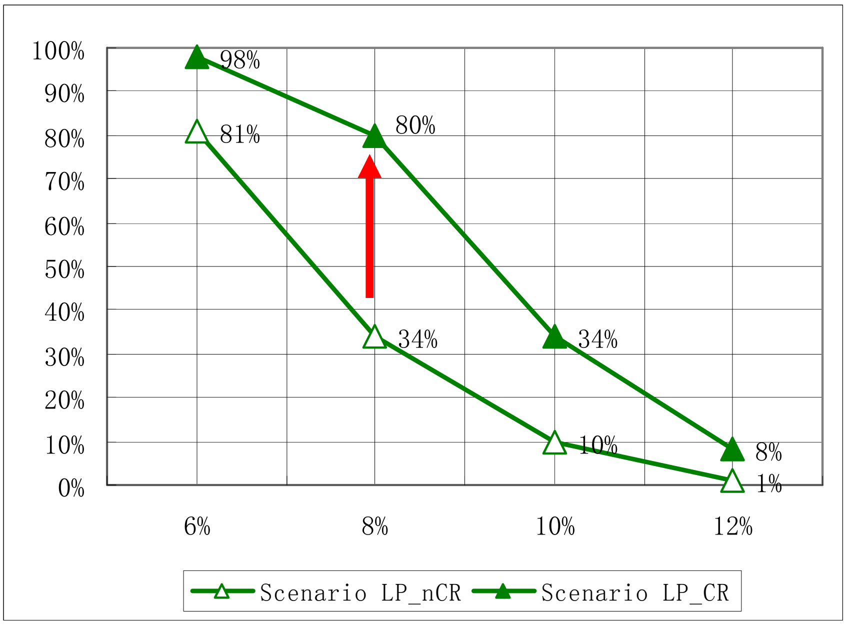


Figure 6 Probability of Retrofitting to Capture in Scenario LP

Closure Possibilities

The option of capturing CO_2 reduces the possibility of early closure of the underlying plant, especially in the LP and HO scenarios. Furthermore, Capture Ready investment also reduces the likelihood of shutdown. For example, in the LP scenario, at a discount rate of 8%, the probability of closure drops from nearly 100% to 75% because of the existence of CCS, while the possibility is further decreased to below 40% if there is a Capture Ready Investment.

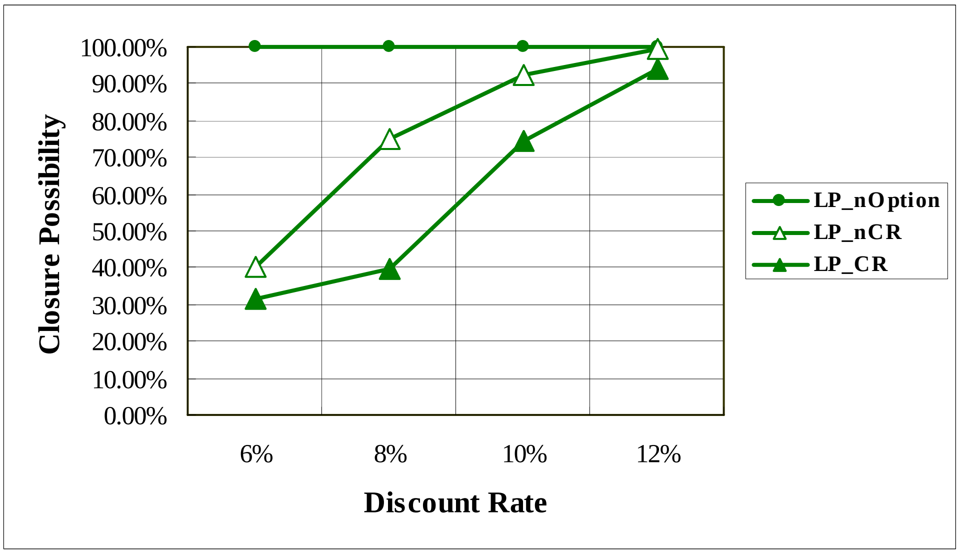


Figure 7 Possibility of Early Termination in a Low Project Value (LP) Scenario

Value of European Style Capture Options

In order to analyse the conditional probability and option value of a specific year, we also modelled the value series of European-style Capture Options (i.e. allow option holders to exercise the option only on a specific date). The result shows the value and the retrofitting probabilities are extremely low after 2032, even in a high option value scenario (Table 10). On the other hand, Capture Ready investment lifts conditional probabilities significantly especially through 2032 (Figure 8).

The European Style Option Value in HO Scenario							
6%_nonCR	2017	2022	2027	2032	2037	2042	2047
spot	0	0	0	0	0	0	0
Average	1592	1183	581	31	0	0	0
Std Dev	546	771	690	205	0	0	0
Std Err	17.26	24.37	21.83	6.48	0.00	0.00	0.00
Max payoff	2872	3255	3591	2476	0	0	0
Min payoff	0	0	0	0	0	0	0
6%_CR	2017	2022	2027	2032	2037	2042	2047
spot	0	0	0	0	0	0	0
Average	2427	1812	1015	268	1	0	0
Std Dev	551	865	828	565	20	0	0
Std Err	17.41	27.36	26.19	17.85	0.63	0.00	0.00
Max payoff	3589	3700	3335	2901	516	0	0
Min payoff	0	0	0	0	0	0	0

Table 10 Value of European Style Options in a Higher Option Value Scenario

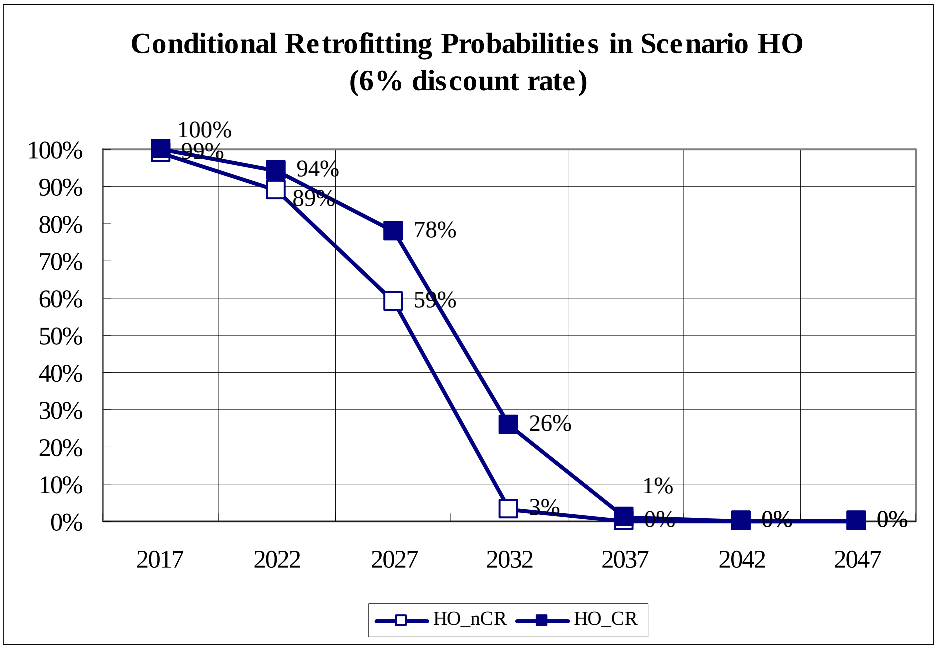


Figure 8 Conditional Probabilities of Retrofitting to Capture in HO Scenario

5.4 Discussion

The value of a Capture Option is significant in some scenarios, as the model results imply that a Capture Option for a 600MW SCPC project in China is worth CNY113m to 1255m at an 8% discount rate in either *LP scenario* or *HO scenario*. However, in scenarios such as *LO* or

HP, in which the costs of emissions is relatively low, the value of the Capture option is inconspicuous. At the same time, an option to retrofit the plant to Capture may reduce the operating risk associated with the cost of future carbon emissions reductions.

Capture Ready investment lifts the value of Capture Option. The gross value of Capture Ready varies from CNY3m to CNY633m ($0.4m to $84.4m) at an 8% discount rate and the number reduces dramatically when discount rate goes up. To maximise the returns from issuing a Capture Option, plant owners may invest in Capture Ready if the required Capture Ready investment cost is less than the gross value of Capture Ready.

Aside from the economic benefits, investing in Capture Ready significantly increases the probability of retrofitting to Capture becoming economic and reduces possibility of early termination of power plants, both of which may assist government's potential regulatory policies for decarbonising fossil fuel plants and leads to mandates Capture in the future. Of course, for this very reason, others might resist the introduction of Capture Ready.

In January 2007, a preliminary report published by the China Electricity Council (CEC, 2007) showed the total installed coal fired capacity at the end of 2006 is 484.05 GW increased by over 90 GW in a single year. However, none of the planned or in-construction plants been designed as Capture Ready. Assuming an 8% discount rate and that a 1% average capital outlay would be needed to meet Gibbins' Capture Ready definition, in *LP scenario*, roughly about CNY 48 billion ($6.4b) has already been lost for the Capture un-Ready of new thermal installed capacity in 2006 alone based on this model. As the latest projections from NDRC (2007) imply that new coal-fired capacity will grow by at least 50 GW per year through 2010, it is crucial to recover the value of Capture Ready.

5.5 Limitations and Scope for Future Work

Cost of Carbon Emissions

We estimate a 2006 benchmark carbon price (cost) based on the current carbon price of CDM projects (CDM price) in China. However, as the project would operate from 2012 to 2050, the real shape of the carbon price may be much more complex than the carbon price assumed here. On the other hand, as of October 2007, there is still no approved methodology for including CCS in the CDM. Another critical factor is the timing and severity of any carbon constraints assumed by China at some later date. Both the availability of CDM credit and Chinese constraints could be the subject of a more detailed uncertainty analysis.

Likelihood of Alternative Scenarios

The probability distribution of the different scenarios is unknown, and we have not chosen a single base case or reference scenario in order to describe the range of plausible outcomes. Nevertheless, associating probabilities with each scenario using methods such as expert elicitation would improve the model and narrow the band of outcomes, leading to a more precise value of Capture Options and Capture Ready.

Chinese Policies on Climate Change

The scenarios considered are those where the decision to capture CO_2 is based on economics, whereas regulatory scenarios mandating capture are not included. Currently, China is not obliged to meet any carbon emissions reduction target and average per capita income in China is far below those countries that have assumed obligations to date. It is virtually impossible to predict whether and when the Chinese government will announce a policy to require fossil fuel plants to capture CO_2 or impose a punitive carbon tax, but recent news highlighting China overtaking the US as the leading emitter of CO_2 emissions has brought new pressure for Chinese actions (even if the US has a population less than one-quarter the size of China). It seems reasonable to assume that some form of regulatory regime would be put in place well before 2050, the time horizon of our analysis.

Other Operating Flexibilities

The model considers options of closing down the plant ahead of schedule when the economic prospect is unfavourable, but does not take the possibilities of restarting the plant into account. In addition, the options of increasing electricity generation and reducing carbon credit production at favourable economic conditions are not built into the model. Adding additional options may substantially increase the project value.

Technology Barriers and Policy Hurdles

As of 2007, there is no commercial-scale CCS unit built, under construction or approved in China and global experience with full-scale CCS projects involving capture, transport and storage is minimal (IPCC, 2005). Therefore, the uncertainties and potential hurdles from either the technology side or the regulatory side may significantly impair the value of Capture Options and Capture Ready.

The Costs of Capture Ready

The required capital outlay for Capture Ready is not given here, because the cost of Capture Ready can vary widely depending on the original design and location of a plant. Some factors such as property values and distance to storage site will affect the Capture Ready investment needed and transport cost significantly. For new SCPC plants, 1% of capital cost has been used as a reasonable assumption in Table 3 for achieving Capture Ready. Of course, a detailed engineering and economic assessment of a power plant project would need to use project-specific data and might yield quite different estimates. Aggregating across plants, it should then be possible to build up an improved estimate of the capital cost associated with Capture Ready at the typical Chinese plant.

Degree of Capture Ready

The analysis in this section only considers a specific Capture Ready arrangement. In order to optimize the benefit of issuing a Capture Option, alternative configurations of Capture Ready should be evaluated and optimized for the case of real projects.

The Cost of Capital

Throughout the analysis, the discount rate is not affected by either retrofitting to Capture or Capture Ready investment. In theory, the variance (a proxy of risk) of the project value should be reduced after Capture Ready investment or retrofitting to Capture. On the other hand, in reality, the technology, policy and regulatory uncertainties associated with Capture Ready and CCS may increase the discount rate. It is hard to make a quantitative conclusion regarding the net effect. Further research in this area is essential, because the model results are highly sensitive to the discount rate.

Behavioural Finance in the Decision-making Process

The model assumes the investor's decision to build a new power plant, close down a plant, retrofit a plant or include Capture Ready is based on a positive trade-off between risk and return. In reality, some investors will be affected by frame dependence or various heuristic-driven biases (Shefrin, 2007). A survey of decision-making behaviour of key opinion leaders and institutions used when investing in the power sector may therefore improve the model.

Estimates of Transport, Storage and Monitoring Costs

Transport, storage, and monitoring cost data are based on expert estimations found in the IPCC Special Report (IPCC, 2006). However, the report does not mention the dates associated with the cost estimates, which may affect the model results. We assume costs are based on 2006 data and are adjusted by fixed-capital inflation in our model, but a better understanding of the underlying costs overall is necessary.

The On-going Electricity Market Reforms in China

The Chinese electricity market still requires substantial market-oriented reform – recent assessments have found that the on-going reform appears ‘limited to symbolic institutional changes rather than a real renovation of its central-planned style’ (Yang, 2005). In our paper, the option pricing model is not based on a liberalized and competitive electricity market. Therefore, if the Chinese electricity market is liberalized over the time horizon, the model would require substantial modification.

6. Conclusions

Making coal-fired plants Capture Ready is a critical stage on the path to a low-carbon economy in a country such as China where a large number of coal-fired power plants are under construction or being planned but where binding carbon constraints are not imminent. Unfortunately, existing financial incentives are unable to finance Capture Ready – both governments and electric utilities are reluctant to invest. To resolve the dilemma, we suggest that newly built fossil fuel plants, which are not currently considering Capture Ready because of the absence of any incentive, issue Capture Options in order to finance Capture Ready by drawing in foreign investors and others interested in low-carbon investment opportunities.

Not surprisingly, our analysis finds that the value of Capture Options and Capture Ready investments are more attractive in high carbon-price growth scenarios. The potential significant cash inflow from issuing Capture Option may encourage new plants to consider and even optimize Capture Ready arrangements. Furthermore, it may improve stakeholder awareness of the value of Capture Ready. Investors concerned about the growth in Chinese emissions might also become interested in Capture Ready, not only because it raises the possibility of affecting the emissions path in China's rapidly growing power sector but also because the investment would be attractive relative to other options.

Through the analysis, we hope to have begun to answer several major research questions outlined at the end of Section 3.

- How can a Capture Option finance Capture Ready?

If the gross value of Capture Ready is higher than the required capital outlay of Capture Ready, plant owners can invest in Capture Ready to maximize their profits by selling Capture Options at a later date. In theory, a plant owner should finance Capture Ready until the marginal benefits from greater investment in Capture Ready is equal to the marginal cost of the additional capital outlay.

- What is the potential benefit of Capture Ready?

We evaluated a specific Capture Ready proposal for a 600 MW supercritical unit in China and found the gross value of Capture Ready (before capital outlays) to be between CNY3m ($0.4m) and 630m ($84m) using an 8% discount rate. Capture Ready investment may increase the value of the project and reduce the operating risk of the high carbon prices. On the other hand, we find Capture Ready is highly sensitive to the discount rate (required return) of a project. In a high option value (HO) scenario, based on an assumption of 1% additional capital outlays for Capture Ready, the net value of Capture Ready varies from CNY803m ($107m) at a 6% discount rate to CNY43m ($5.7m) at a 12% discount rate.

- What is the value of a Capture Option?

The value of a Capture Option is highly dependent on the assumptions made with regard to electricity price, carbon price and coal price (or the probability distribution of scenarios). In our case study, at a discount rate of 8%, across all scenarios, the gross value of the Capture Option for a 600 MW coal-fired supercritical unit in China ranges from CNY1m ($0.1m) to 627m ($83.6m) without Capture Ready, and from CNY2m ($0.3m) to 1255m ($167.3m) with Capture Ready. The value of a Capture Option is also sensitive to discount rates; for example, under the high option value scenario (HO), the value varies from more than CNY2400m ($320m) using a 6% discount rate down to CNY97m ($12.9m) at 12%. Finally, arguably the most important benefit of a tradable Capture Option is to encourage stakeholders to treat the Capture Option as a valuable asset and Capture Ready as an important investment decision.

Appendix I. Coding Rule for Scenarios and Impacts of Uncertainties

Codes & Impacts of Inputs' Uncertainties				
	Low	***High***	***Impact on Capture Option Value***	***Impact on Project's NPV***
Construction Cycle	ccL	ccH	insignificant	adverse
Year	2	3		
Capacity Load before Capture	cbcL	cbcH	adverse	positive
See Table 3	Low	High		
Capacity Load after Capture	cacL	cacH	positive	positive
See Table 3	Low	High		
Transport, Storage & Monitoring Cost	tmsL	tmsH	adverse	adverse
CNY/mtonCO2	0.6	16.3		
Basic Inflation	infL	infH	adverse	positive
	1.5	4．5		
Carbon Price Growth	cpgL	cpgH	positive	adverse
	4.5%	8%		
Correlation (coal, carbon)	cccL	cccH	adverse	insignificant
	-10%	-60%		
Correlation (electricity, carbon)	cecL	cecH	adverse	insignificant
	20%	80%		
Capture Ready Investment	cr	ncr	positive	positive
(Ignore CR Capital)				
Discount Rate			adverse	adverse
6%, 8%, 10%, 12%				

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