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THE REAL DRIVERS OF CARBON CAPTURE AND STORAGE IN CHINA AND IMPLICATIONS FOR CLIMATE POLICY

RICHARD K. MORSE, VARUN RAI, AND GANG HE

FREEMAN SPOGLI INSTITUTE FOR INTERNATIONAL STUDIES

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Program on Energy and Sustainable Development
Encina Hall East, Room E415
Stanford University
Stanford, CA 94305-6055
http://pesd.stanford.edu

Authors

Richard K. Morse is a research associate at the Program on Energy and Sustainable Development (PESD). Richard leads PESD’s research on global coal markets, which examines the political economy of coal and coal's long term role in the world's energy mix. Other research includes carbon markets, renewable energy markets, and financial markets for energy commodities.

Richard received a bachelor's degree in philosophy from Rice University, where he was awarded the James Street Fulton Prize for the top graduate in the field. He has worked in commodities markets for oil, natural gas, and renewable energy.

Varun Rai is a research fellow at the Program on Energy and Sustainable Development (PESD). Dr. Rai’s research focuses on technologies and policies for carbon capture and storage (CCS), technological innovation and diffusion, and the technology and energy policy of India. He leads the carbon capture and storage (CCS) research at PESD.

Dr. Rai received his Ph.D. and MS in Mechanical Engineering from Stanford with specialization in energy systems and technologies. He holds a Bachelor's degree in Mechanical Engineering from the Indian Institute of Technology (IIT) Kharagpur.

Gang He is a research associate at the Program on Energy and Sustainable Development (PESD). Gang’s research focuses on China’s coal sector and its role in the global coal market, and China’s energy and climate change policy. Other research includes global climate change and clean energy. He leads PESD’s research on China.

Gang received a bachelor's degree in Geography from Peking University and MA in Climate and Society from Columbia University.

The Real Drivers of Carbon Capture and Storage at Scale in China and Implications for Climate Policy

Richard K. Morse, Varun Rai, and Gang He

I. Introduction

The capture and permanent storage of CO_2 emissions from coal combustion is now widely viewed as imperative for stabilization of the global climate. Coal is the world's fastest growing fossil fuel, and coal combustion is now the largest single source of anthropogenic CO_2 emissions, totaling 11.686 billion metric tons in 2006. By comparison, oil and natural gas use accounted for 10.768 and 5.445 billion tons of annual CO_2 emissions in 2006, respectively.[1] Driven by increasing coal consumption in China and India in particular,[2] growth in global coal use shows no signs of slowing. This trend presents a forceful case for the development and wide dissemination of technologies that can decouple coal consumption from CO_2 emissions—the leading candidate technology to do this is carbon capture and storage (CCS).[3] Indeed, IEA climate mitigation scenarios call for CCS worldwide to provide overall emissions reductions of 5-10 billion tonnes of CO_2 annually ($MTCO_2$/yr) by 2050 (14-19% of the total warming-gases emissions reductions in IEA model scenarios). Because China's coal-fired power sector is the world's largest,[4] the IEA states that CCS in China will have to supply 20-25% of total emissions reductions, and over 60% of those reductions will need be applied to coal-fired power plants.[5]

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[1] *CO_2 Emissions from Fuel Combustion*, IEA 2008.

[2] The IEA (*World Energy Outlook* 2008) predicts under its reference scenario that China and India alone will consume 8.1 billion metric tons of coal by 2030, driving GHG emissions in the developing world to new heights.

[3] *IPCC Special Report on Carbon Dioxide Capture and Storage*, 2005 and *CO_2 Capture and Storage: A Key Abatement Option*, IEA 2008. For the purposes of this paper we treat CCS as referring to carbon capture and geological storage.

[4] By 2030 it is projected that China will have 1332 GW of coal-fired generation capacity, compared to 583 GW in the US and EU combined (*World Energy Outlook*, IEA 2008).

[5] *CO_2 Capture and Storage: A Key Abatement Option*, IEA 2008.

At the same time, the current deployment of CCS is nowhere near the implied requirement to stay on pace with IEA projections, and a broadly applicable commercial model for CCS is yet to be demonstrated. The majority of existing projects have required favorable niche circumstances (for example, government subsidies or special funding) or niche applications (often the opportunity for captured CO_2 to be used in enhanced hydrocarbons recovery) to make high costs recoverable. Also problematic is that only a few of these CCS projects and technologies have been applied to coal-fired power plants.[6] There is currently only one fully-integrated coal power plant with CCS in the world: Vattenfall's Schwarze Pumpe station in Germany. And even there, the scale of carbon capture is an order of magnitude smaller than for a fully commercial-size power plant.[7] The key factors that have so far deterred investments in CCS projects include technological uncertainty, especially regarding performance of capture technologies at scale; high costs; regulatory uncertainty including over liability for sequestered CO_2; and lack of clear carbon policy that could provide a revenue stream for CO_2 capture. Though recent government stimulus packages have triggered a wave of new government subsidies that will likely kick start a handful of CCS demonstration projects globally, an enormous gap remains between the implied need for CCS and a path to viable commercial deployment.

China simultaneously presents the most challenging and critical test for CCS deployment at scale. Its coal sector is the world's largest and the rapid industrialization of China is inexorably tied to the same process that fueled the West's development—burning coal. However, the stark reality to be explored in this paper is that China's incentives for keeping on the forefront of CCS technology learning do not translate into incentives to massively deploy CCS in power plant applications as IEA scenarios would have it. In fact, fundamental and interrelated Chinese interests—in energy security, economic growth and development, and macroeconomic stability—directly argue against large-scale implementation of CCS in China unless such an implementation can be almost entirely supported by outside funding. In this paper, we consider how these core Chinese goals play out in the specific context of the country's

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[6] Rai, V., Chung, N. C., Thurber, M. C., and Victor, D. G., "PESD Carbon Storage Project Database", PESD Working Paper #76, Stanford University, November 2008.

[7] Schwarze Pumpe is a 30 MW oxyfuel plant. See http://www.vattenfall.com/www/co2_en/co2_en/879177tbd/879211pilot/879254schwa/index.jsp for more details. Reports in July 2009 indicate that Schwarze Pumpe has not actually sequestered the CO_2 that it captures due to opposition from local governments. If true, there may be no fully integrated CCS plant in the world at the time of this papers' publication.

coal and power markets, and we use this analysis to draw conclusions about the path of CCS implementation in China's energy sector. Finally, we consider possible leverage points for international climate policy to spur the development of CCS in China.

We make the following four principal observations:

First, we argue that the primary driver of current CCS projects in China is the strategic development of its energy security agenda, with particular emphasis on diversity of energy supply, reliable and cheap electricity, and the development of domestic intellectual property for energy technologies. Unfortunately, many analysts who are rushing to declare that CCS has arrived in China are confusing these motives for an enthusiastic embrace of CCS for purposes of large scale CO_2 emissions reductions. A crucial distinction must then be made: while these energy security drivers are likely to foster the development China's CCS demonstration efforts (as we are likely to witness in the near term), they do not translate into incentives to deploy CCS at scale. In fact, as we argue later, CCS at scale will place a heavy burden on China's coal supply chain and is more likely to harm China's energy security than to help it. The only manner in which CCS would concretely serve energy security needs would be if China were subject to a stringent greenhouse gas reduction regime at some future time, in which case CCS could facilitate the use of domestically-available coal (for either power or for transport using coal-to-liquids technology). However, we argue that such a scenario is likely many years from being a reality, mainly because China has no core interest in agreeing to and enforcing such a regime on itself until it has developed economically to the point where a large domestic constituency values climate change action as much as rapid economic growth. But this aspect of energy security does explain why China remains interested in developing proprietary CCS technology in the demonstration phase. The possibility that some future scenario might leave China dependent on CCS in order to use domestic coal provides motivation for the country to develop strong indigenous technology *capability* in this area (which might additionally lead to commercial opportunities down the road) so that it can control its energy destiny if CCS ever becomes a necessity. Thus, technology demonstration initiatives like the GreenGen plant at Tianjin will continue to be popular, but these should not be confused with enthusiasm for wide deployment of CCS in China soon.

Second, deployment of CCS at any serious scale in China (as many climate models imply) could in fact have very detrimental effects on China's energy security by stretching to the breaking point a coal supply chain that is already overburdened at many critical points. As noted above, a widely overlooked point about large-scale implementation of CCS in China is that it would almost assuredly result in significantly more coal use due to the parasitic load from CCS (typically estimated at 20-30%, although improved technology in the future could bring this number down). China's coal supply chain has some structural issues—among them the mismatch between the location of reserves and points of energy consumption that requires a massive and already overburdened transportation infrastructure—that make it difficult to rapidly (and cost-effectively) expand supply even though reserves are plentiful. If every coal plant on which CCS is installed will require 20% more fuel on average,[8] energy planners will need to expand coal supply and the supply chain that much more to accommodate the technology. Moreover, because significant investment in the bottlenecks in coal supply will be required, the full costs of CCS at scale in China could be significantly higher than the already daunting figures for CO_2 capture, transport, and injection when one takes into consideration the costs of additional rail, port, and shipping infrastructure.

Third, the Chinese government's non-negotiable desire for cheap power to fuel economic development and keep inflation in check precludes cost recovery through higher electricity prices for CCS at scale. This constraint will make it even more difficult for CCS for power to develop and scale up in China. In 2008, this structural problem was illustrated by the inability of Chinese generators to incorporate the full cost of their primary input, coal, into the electricity price. A huge run-up in coal prices caused massive losses among Chinese generators. If China's power sector is structurally unable to accommodate fluctuations in fuel prices, it is difficult to see how it can support the massive investments that would be required for CCS. Special government subsidies may be able to fund isolated CCS projects, but without power markets that allow for cost recovery, rapid scaling of the technology in China is likely to prove elusive.

Fourth, in the absence of viable financial models for domestic funding of CCS, international finance will be crucial to the realization of CCS at scale in China. A handful of internationally-funded marquee projects are now beginning. But current international policy mechanisms for engaging the developing world, mainly the UN's Clean Development Mechanism, are not well matched to the scale of the CCS challenge and will need to be reformed if they are to stimulate CCS investment at a scale that will meaningfully impact global CO_2 emissions. A further complication of international finance strategies may be political: countries may be disinclined to provide the substantial funding required for CCS when the associated jobs and technology learning accrue to an economic competitor like China.

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[8] Calculated using "Efficiency Loss" figures on p.65 in *CO_2 Capture and Storage: A Key Abatement Option*, IEA 2008.

These observations have important implications for emissions mitigation efforts. First, the climate policy community needs to understand in a more nuanced way the motivations behind Chinese activities in CCS, which are largely driven by factors other than an interest in CO_2 mitigation, in order to design effective policy. Efforts to engage China in joint technology development on CCS will likely find a receptive audience in the country, as will international funding models. But the assumption of inherent Chinese motivation for wide CCS deployment, on the other hand, will likely lead to disappointment as actual results fall far short of outside projections. If such deployment is deemed necessary for the stabilization of the global climate, concerned nations will likely need to play a central role in picking up the (sizable) bill. Second, the climate modeling community needs to move beyond understanding CCS costs in terms of just capture, transport, and storage. Any realistic analysis must capture the full costs of CCS—including through the entire coal-to-power value chain—in order to really understand the potential for CCS uptake in China.

This paper is split into three sections. Section II explores the underlying drivers for current CCS activities in China. Section III examines some serious impediments to CCS that have thus far received scant attention. We argue these issues will be critical for any serious evaluation of CCS at scale in China going forward. Finally, Section IV considers how to promote deployment of CCS in China, emphasizing the importance of well-designed financial and strategic incentives.

II. The Strategic Drivers of Current CCS Efforts in China

China's increasing involvement in CCS projects should be understood in the context of its overarching energy-security agenda. That agenda is complex, but at its heart are security of fuel supply, availability of cheap and reliable electricity supply, and access to key energy technologies. Assessing how CCS could help contribute to longer-term Chinese energy-security goals is the primary motivation behind China's CCS efforts so far.[9] The current progress of CCS in China is being largely driven by considerations other than climate change.

China's CCS efforts began with a series of central-government policies supporting CCS research and development. In late 2005 the Ministry of Science and Technology signed a CCS memorandum that initiated government-sponsored CCS research. In 2006 the National Medium

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[9] IEA has done some analysis about CCS development in the context of China's clean coal development; see *Cleaner Coal in China*, IEA 2009.

and Long-term Science & Technology Development Plan (2006-2020) [10] formally designated CCS a "cutting-edge technology" in pursuit of clean and high-efficiency use of coal (a broader high-priority energy target in China). China's Science & Technology Action on Climate Change 2007[11] established that CCS efforts will focus on RD&D, capacity building, and demonstration of CCS technologies. China's State High-Tech Development Plan, the 863 program,[12] later allocated 300 million RMB (43 million USD) to CCS technology development from 2008 to 2010 and further formalized China's pursuit of the technology.[13] While these policies support important CCS research in China, they are not geared towards CCS deployment.

A few CCS projects that span a range of technologies and commercial models (see Table 1) are now being developed for the Chinese market.[14] Broadly, CCS could disseminate at scale in China in three contexts: industrial applications of CCS, for example at steel and cement plants; fuel transformations, for example coal to synfuels, especially coal to liquids (CTL); or CCS at power plants, either pre- or post-combustion.[15] Of these, the last two options are generally considered to have better scale-up opportunities and to be better suited for mitigation of China's growing emissions: the IEA projects that in 2050 nearly 25% of CCS in China will be fuel-transformation-related CCS, while another 60% will be power-generation based CCS.[16] Accordingly, in our analysis we focus only on these two major applications of CCS.

The first major CCS projects in China—Shenhua's CTL project in Ordos, Inner Mongolia and the GreenGen IGCC plant in Tianjin— have progressed rapidly because they explore technologies with implications for China's long term security of energy supply.[17] CTL could provide China with alternatives to importing oil, and the GreenGen IGCC plant tests a coal

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[10] http://www.most.gov.cn/kjgh/. See Article 5: Advanced energy technology.

[11] http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File199.pdf

[12] The name 863 comes from the fact that the program was created in the third month of 1986. The program is intended to stimulate the development of advanced technologies in a wide range of fields for the purpose of rendering China independent of financial dependency on foreign technologies.

[13] Page 154 of *CO_2 Capture and Storage: A Key Abatement Option*, IEA, 2008.

[14] We argue that risk and the ability to mitigate it are leading indicators of the viability of CCS models in energy markets.

[15] These models can largely be understood based on technology. Our goal here, however, is to broaden the analysis to encapsulate broader commercial conditions.

[16] *CO_2 Capture and Storage: A Key Abatement Option*, IEA 2008.

[17] Huaneng Beijing Thermal Power plant is not a major CCS effort as its capture and sequestration volumes amount to 3,000 tons per year, which is stored in beverages.

combustion technology that would reduce coal demand by increasing efficiency while also reducing local air pollution. (The CCS phase of GreenGen is slated to come later and remains somewhat of an afterthought in comparison with the IGCC development work.) In the case of post-combustion technologies which do not have potential benefits for fuel security, China has been slower to undertake major projects and is eager to spread risks across international partnerships. In the remainder of this section we focus in particular on the Shenhua CTL and GreenGen projects and how these climate-friendly efforts align with Chinese non-climate objectives.

Table 1 Current CCS Projects in China

CCS Projects	Technology	Partnership model	Financial arrangement	Status (Aug. 2009)
GreenGen Corporation	IGCC[18] Pre-combustion de-carbonization Gasification or partial oxidation shift plus CO_2 separation	Huaneng with other 7 state-owned energy companies: China Datang Group, China Huadian Corporation, China Guodian Corporation, China Power Investment Corporation, Shenhua Group, State Development & Investment Corporation, China Coal Group, Peabody Energy	Registered capital: RMB 300 million (about USD 44 million) Huaneng 51%, and other 7 in the group 7% each. Total Investment will reach RMB 7 billion.	Under construction
Shenhua CTL	Coal to synfuels (direct coal liquefaction)	Shenhua Group Sasol West Virginia University	USD 1.4 billion	CTL operational, CCS expected to start in late 2009

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[18] IGCC stands for Integrated Gasification Combined Cycle. There are some other active IGCC projects with studies of CO_2 capture in China: the Dongguan IGCC project, the Huaidian Banshan IGCC, and the China Power Investment Corporation IGCC project.

Huaneng Beijing Thermal Power[19]	Post-combustion	Huaneng Australia CSIRO	USD 4 million research project by CSIRO	Operational since 2008
Near Zero Emission Coal[20]	R&DD	UK China Ministry of Science and Technology	£3.5 million from the UK Government's Department of Energy and Climate Change	In planning stages
COACH project (Cooperation Action within CCS China-EU)[21]	R&DD	COACH project groups 20 partners (R&D, Manufacturers, Oil & Gas Companies, etc...), 12 for Europe and 8 for China	Partially funded by European Union	In planning stages

II.a Shenhua CTL

Shenua's CTL project is slated to become the first major CCS project in China, but it is not primarily driven by climate concerns. The strategic logic of coal-to-liquids technology is all about replacing oil imports.[22] Integrating CCS into CTL processes would further boost security of oil supply by providing high purity CO_2 streams with almost no additional capture cost—the largest cost of CCS in power generation (see later)—that could be pumped into declining oil reservoirs to yield previously unrecoverable oil supplies (enhanced oil recovery, or EOR). To prove the relevant coal-to-synfuels and CO_2 EOR technologies, Shenhua's Inner Mongolia project plans to produce one million tonnes of liquid transport fuel annually and expects to begin capturing and sequestering CO_2 in 2009. The 3.6 million metric tonnes of CO_2 that the project

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[19] Huaneng is reported to plan a launch of its second pilot carbon capture project in Shanghai at the end of 2009, but high costs are holding back further progress. http://www.reuters.com/article/GCA-GreenBusiness/idUSTRE54O15Y20090525

[20] See more details at official website: http://www.nzec.info

[21] See more details at official website: http://www.co2-coach.com/

[22] As Chinese economic growth has become increasingly contingent upon oil imports—in 2008 China imported 179 million tonnes of crude oil (49.8% of its requirement) at a cost of about 19 billion dollars – China's interest in CTL as an energy security contingency plan has grown despite its high cost. China has 114.5 billion tons (13.5% of world total reserves) of coal reserves, but only 2.1 billion tons (1.3% of world total) of oil reserves and 66.54 trillion cubic meters (1.1% of world total) of gas reserves.

will generate annually will be used for EOR in nearby declining hydrocarbon reservoirs, yielding new oil and gas revenue streams that will bolster the project economics.[23]

Because coal is China's largest domestic energy resource, CTL serves as a hedge against oil-import dependence. Indeed, deployment of CTL in China, as in other places, is closely linked to oil prices: in 2008 when the oil price crested at $147, China had 12 CTL projects in the pipeline. Many projects have been put on hold since oil prices crashed, but in addition to the Shenhua project, two other CTL plants are being developed by the Yitai Group and the Lu'an Group.[24] There are strong indications that Chinese CTL investments may surge again in the near future.[25,26]

But CCS for CTL in China has limited relevance to global CO_2 mitigation goals, for a number of reasons. First, CTL is not currently a major source of emissions in China, and its growth is much less certain than the growth of coal-fired power. Second, CCS on a new CTL plant essentially results in a transport fuel that is roughly net equivalent in carbon emissions to oil; it only creates a significant net benefit for climate relative to the very high net emissions of CTL without CCS. Third, the simplicity of CO_2 capture from a CTL process means that technology learning from such applications is not transferable to the largest source of CO_2 in China – coal combustion at power plants. Relative to post-combustion CCS, where the capture process represents over 50 percent of CCS costs, or IGCC-CCS where the costs of IGCC alone have thus far proven prohibitive, capturing CO_2 from a CTL process is much cheaper and more straightforward.[27] Indeed, removing most of the CO_2 from the gaseous stream after coal

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[23] http://www.netl.doe.gov/publications/proceedings/08/CO2E/PDF/session%201/2008.5.Hangzhou%20CO2%20forum-EN.pdf

[24] Yitai and Lu'an both planned test plants that would produce 160,000 tons of liquid fuel annually and use indirect coal liquefaction technology developed domestically by the Institute of Coal Chemistry in Shanxi.

[25] Reuters and Xinhua reported on June 11, 2009 that Shenhua intends to invest 400 billion RMB in facilities to convert coal to oil, methanol, and gas, adding the capacity to convert 100 million tons of coal into 39 million tons of oil and chemical products by 2020. On June 22, 2009 Reuters and Xinhua reported that a CTL partnership between Shenhua and Sasol will begin construction in 2010 in the Ningxia region. The project plans to consume 3.2 million tons of coal annually, producing 80,000 bbls of oil output daily.

[26] CTL requires large amounts of available water resources. Producing one tonne of oil requires roughly four tonnes of water. Water scarcity in West China is likely to constrain the expansion of CTL.

[27] The CO_2 streams available during coal-gasification processes are at an order of magnitude higher partial pressure than those in the flue-gas exhaust of power plants. This not only reduces the size and complexity of the required

gasification is necessary to improve the yield of liquid fuels during the synthesis step of the Indirect Liquefaction process. In the Direct Liquefaction process used by the Shenhua CTL project, a pure stream of CO_2 also becomes available (with no capture equipment) during the production of hydrogen, which is used in the hydrocracking step to break down the structure of coal. Therefore, while CTL is certainly a response to dependence on the global oil market for energy imports, CTL-CCS does not address the major challenges for the largest source of CO_2 in China – coal combustion at power plants.

CTL-CCS projects are only likely to be pursued where EOR opportunities exist. CTL projects are very capital intensive in their own right, which means that project owners look for stable revenue streams over long-time horizons. Adding carbon storage increases capital requirements and adds further financial risk to these projects. These risks are not likely to be justified absent additional revenue streams from incremental oil recovery.[28]

II.b GreenGen IGCC

CCS technology integrated with IGCC,[29] as envisioned by GreenGen, is now the major focus of state-supported CCS for power plants in China. The main advantages of CCS with IGCC are the high combustion efficiencies of IGCC and the relative ease of CO_2 capture compared with post-combustion CO_2 capture (where the CO_2 partial pressure is much lower and hence capture is more complicated and expensive). While no IGCC project has yet been deployed, the central government's 863[30] and 973[31] R&D programs favor developing CCS in concert with IGGC.

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capture systems, but it also permits the use of commercially available and relatively cheap capture technologies (*IPCC Special Report on Carbon Dioxide Capture and Storage*, 2005).

[28] Volatility of oil price hampers CTL projects, which are more attractive where oil prices remain high over the long run. Given that carbon storage with CTL is favored only when EOR opportunities are available, volatile oil or low oil prices doubly hamper carbon storage based on CTL.

[29] In IGCC steam and oxygen are used to gasify coal into syngas, a mixture carbon monoxide (CO) and hydrogen (H_2). After removing impurities (H_2S, COS, etc.), the syngas is passed through a water-gas shift reactor that generates CO_2, which is then captured in the next stage. The remaining syngas is combusted in a gas turbine to generate electricity. The hot flue-gas stream of this stage is used to generate steam that is used in a steam cycle to generate more electricity (hence 'combined cycle').

[30] The national high technology research development program, named for starting year and month.

The drivers for making IGCC power plants a state priority in China are again rooted in energy security concerns (there are also co-benefits in the form of reduced local pollution and synergies with chemicals production).[32] First, China's own internal energy policy provides strong incentives for developing IGCC as an efficient coal combustion technology.[33] China's national energy-efficiency policy targets a 20% drop in energy intensity of GDP from 2005 levels by 2010 and depends heavily on generating electricity from coal more efficiently. In addition, long-term planning for the reliability of electricity supply necessarily emphasizes using coal efficiently, as remaining domestic resources are finite and production and associated transport costs will increase as the best and cheapest coal reserves are exhausted over time.

Second, developing intellectual property and technological capability in IGCC will save China from dependence on foreign power plant manufacturers in the future;[34] the concern is that foreign technology is expensive and may be subject to political restrictions on availability, as is already the case for some technology. For this reason, China has directed Xi'an Thermal Power Research Institute to develop a domestic gasifier and turbine. China has pursued a similar strategy for existing state-of-the-art coal-combustion technologies through an aggressive national program for developing domestic supercritical and ultra-supercritical coal-combustion technology.[35] An additional benefit for China of developing indigenous technology is the commercial opportunity to export it to other countries. The appeal of domestic IP and future opportunities for export are perhaps the strongest motives for China to investigate carbon-capture technologies as well.

The potential direct benefit to Chinese energy security through higher efficiency and the development of potentially lucrative domestic IP help explain why the Chinese government is

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[31] The national key fundamental research development program, named for starting year and month.

[32] Most analysts predict that CCS integrated with IGCC would reduce prohibitive capture costs, and thus is the most viable path forward for integrating CCS into coal-fired plants, despite the fact that IGCC technology itself is largely commercially unproven. IGCC could also have significant environmental benefits when compared to conventional coal combustion, reducing emissions of NOx, SO_2, and mercury.

[33] The average efficiency of China's coal plants is between 32-34%, and IGCC might reach 40-45% efficiency.

[34] China has historically relied on foreign power-plant technology. Today, many foreign firms operate JVs with Chinese companies to produce equipment inside of China. The Chinese government has emphasized the pursuit of domestic intellectual property as a strategy for weaning dependence on foreign firms.

[35] In 1995-2000, NDRC initiated the "Development of 600MW supercritical coal-fired power unit" project. In 2001-2005, MOST's 863 project of "Ultra-supercritical coal-fired power generation technology" further advanced the domestic RD&D efforts.

putting its own capital behind GreenGen, the world's leading IGCC-CCS project. The financial risk of GreenGen is significantly borne by the government through eight state-owned companies (see Table 1).[36] While similar projects elsewhere (for example, FutureGen[37] in the US) have struggled to get started due to large capital requirements and uncertain benefits that deter first-movers, full-fledged government support through state-owned companies makes GreenGen's implementation highly likely. The information that GreenGen provides the Chinese government about the costs of IGCC and associated CO_2 capture will be crucial as China prepares the roadmap of its power generation build-out beyond 2020.

GreenGen is centered around a 400 MW IGCC coal plant in Tianjin. The project plans to incorporate polygeneration (the flexibility to produce a combination of electricity and chemical feedstocks) and CCS. The project is envisioned in three stages:[38]

- Stage One (2005-2010): 2000 t/d gasifier, 250 MW IGCC operation, hydrogen production and CO_2 separation at pilot scale;
- Stage Two (2010-2015): 3000 t/d gasifier, 400 MW IGCC, hydrogen production and CO_2 separation at 100 MW scale;
- Stage Three (2015-2020): 3000 t/d gasifier, 400 MW IGCC with full scale CO_2 capture.

An important observation about GreenGen's development sequence is that CCS remains for the moment distinctly an afterthought relative to the more strategically important goal of developing IGCC. While the IGCC plant is physically under construction at the moment as part of Stage One, the design of any carbon capture system is still very much on the drawing board, and carbon storage is even further from a reality, with no CO_2 storage sites having been selected at this point.

Looking beyond GreenGen, integrating CCS into IGCC plants looks to be the most promising route for deployment of CCS for power in China, because it both addresses emissions in the power sector and is well aligned with China's own incentives on efficiency and local pollution, but several key barriers remain. First, IGCC itself has to be proven both

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[36] Peabody Energy, a US coal company, is also seeking participation in GreenGen.

[37] Two of FutureGen's major backers, American Electric Power and Southern Company, backed out of the project in June 2009 just weeks after the Obama administration confirmed renewed funding for the project.

[38] From GreenGen company website.

technologically and commercially in the Chinese market. The current push for IGCC in China envisions gaining efficiencies and additional revenue streams by integrating multiple processes—power, process heat, and chemicals—in order to make the technology cost competitive.[39] Second, the commercial and technological integration of CCS into IGCC needs to be proven.

II.c Other CCS Projects and International Partnerships

China is leveraging international support for developing CCS wherever possible, but especially in cases in which domestic benefits are less clear. It is not a coincidence that the projects with fewest direct benefits to China are the ones that involve international financing and technology sharing models. These projects have tended to progress at a slower rate than those inherently motivated by China's security interests.

Several international CCS research efforts are underway in China. Australia is a partner in Huaneng's Beijing post-combustion capture demonstration plant. The EU is also supporting the development of CCS in China. In late 2007 an EU-China MOU called for "research of near zero emissions coal power generation technology through carbon capture and storage."[40] That agreement spawned the Near Zero Emissions Coal project between China and the UK, which aims to research and develop an IGCC polygeneration CCS demonstration project by 2014.[41] The EU continues to advocate financing of CCS projects in China and in June 2009 declared that it will allocate €60 million to CCS in China and develop a funding mechanism for NZEC.[42] In May 2008, Japan and China announced a cooperative project to capture CO_2 from a Chinese coal-fired power plant and inject it into a Chinese oil field for EOR. While all of these projects certainly represent useful research efforts, they do not represent a level of investment comparable to the Shenhua CTL and GreenGen IGCC projects, suggesting again that finance and progress will be closely correlated to China's energy security interests. And for now, those interests are

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[39] See Hengwei Liu, Weidou Ni, et al., "Strategic thinking on IGCC development in China", Energy Policy, Volume 36, Issue 1, January 2008, Pages 1-11

[40] http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/er/97355.pdf

[41] http://www.nzec.info/en/what-is-nzec/

[42] Sheppard, L., "Communication on financing CCS and other clean carbon technologies in emerging and developing countries", European Commission 2009.

not well aligned with installing post-combustion capture on the biggest source of emissions in China – the existing 600 GW fleet of conventional coal plants.

III. Obstacles to Wider Deployment of CCS in China

As described in the previous section, China's prioritization of CCS technology demonstration projects provides a good window into the inherent motivations behind the country's efforts. But the fact that a few projects are being enthusiastically pursued because they line up with longer-term energy security goals should not be taken to indicate that wider deployment of CCS in China is likely in the near future, particularly in the power sector. Deployment of CCS at scale has not yet been successfully demonstrated in any country, due to obstacles including high costs, uncertain storage conditions and capacity, and the absence of suitable regulatory frameworks. Beyond these universal barriers, though, implementation of CCS in the Chinese power sector presents two special impediments that have not been fully considered in most analyses: the structure of the power market and the supply chain for coal. These formidable obstacles need to be understood in order to gauge the true potential of CCS in China.

III.a The Structure of China's Power Market Constrains CCS Cost Recovery

Depending on the technology, adding CCS is estimated to increase the cost of generating coal-fired power by 40-80%.[43] IGCC with CCS is estimated to increase electricity cost by 40-60% (on top of cost of electricity from IGCC), while post-combustion CCS will increase electricity costs by 60-80% (on top of cost of electricity from subcritical or supercritical coal combustion without CCS). No matter what technology goes forward as the leading contender for deployment of CCS, the costs will be daunting. In the European and US markets, policymakers need to consider how to cover these costs through some combination of carbon market incentives, subsidies, and increased end-user electricity prices. The Chinese power sector, on the other hand, is not market-oriented, and regulation of the energy system is largely driven by the political priorities of the central government. As we will explore in the remainder of this section, the resulting complex organization and inflexibility of Chinese energy markets makes it uniquely

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[43] *IPCC Special Report on Carbon Dioxide Capture and Storage*, 2005 and *Carbon Capture and Storage: A Key Abatement Option*, IEA, 2008.

difficult to sustainably recover the costs of CCS. Chinese energy markets in general exist in various states of reform and liberalization; for the purposes of CCS, the most relevant markets are the coal market and the power market, where the relative imbalance of reform creates serious problems.[44]

China now has mature markets for coal that are increasingly exposed to international prices. As a market-based coal sector has evolved, it has not been immune to price volatility. In 2008 alone, the price of coal at the leading port, Qinhuangdao, mirrored international price volatility and fluctuated from 580 to 950 RMB,[45] reaching historical highs before crashing again.

The power market, however, is not market-oriented. China's central planning apparatus, the National Development and Reform Commission (NDRC), keeps tight control over electricity prices in China in order to meet its larger socio-political agenda. Reform and liberalization of China's power markets remains a distant prospect.

The conflict that arises between unevenly reformed coal and power sectors illustrates a key problem for CCS in the Chinese energy system: the power market cannot internalize increased costs. This means that the Chinese power market is designed in a way that makes it nearly impossible for it to deploy a commercially-viable CCS model on its own.[46] In 2008, much of the Chinese power market could not even bear the cost fluctuations of its primary input – coal. Coal currently is the largest cost for power generators in China, and when the coal price rises in response to supply shortages or other market events, the power sector cannot proportionally increase electricity prices in response.[47] In 2008 coal prices reached new heights

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[44] For a detailed history, see Peng, Wuyuan, "The Evolution of China's Coal Institutions", PESD Working Paper #86, Stanford University, August 2009.

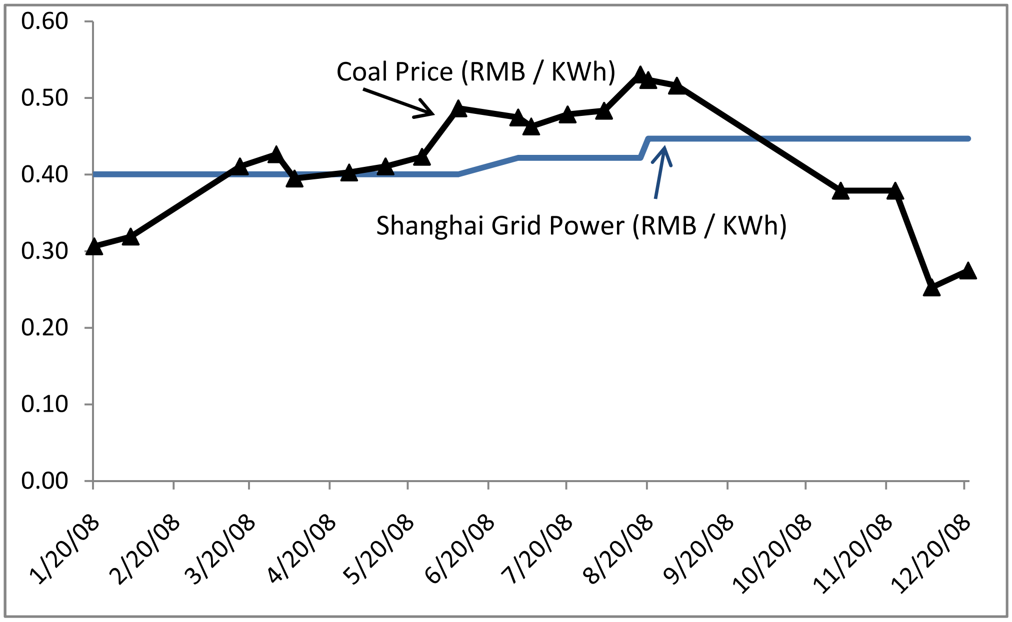
[45] Historical data from China Coal Transportation and Distribution Association, with average heat content of 5800kcal/kg.

[46] There is precedent for the NDRC allowing power plants with more advanced environmental controls to charge slightly higher tariffs. It allows a price increase of 1.5 cents / kwh for the installation of FGD. However, these increases are not well matched to the costs of CCS. Although special power tariffs may be allowed for demonstration plants, CCS deployed at beyond the demonstration phase would entail a significant increase in power prices. In the absence of cost recovery by pass-through in the power price, it is likely significantly larger direct subsidies would be required.

[47] China tried to use a coal-electricity price linkage system to incorporate the coal cost into the power tariff. The system was proposed in 2004 and suggests that when coal price raise 5% in 6 months, the power tariff will adjust accordingly. In May 2005, NDRC adjusted the power tariff with 2.52 cents RMB increase, followed by another

due to transport constraints and the inability of the Chinese coal sector to keep up with booming demand. The price spike could not trump politics, and power generators were forced to operate at massive losses—it is reported that Chinese power companies lost an estimated 70 billion RMB (40 billion RMB for the Big Five only) in 2008.[48] China's state-owned power generators are often forced by the government to operate at losses when independent power producers simply shut down. Figure 1 illustrates how tight control of power prices affects the profitability of coal fired generators (for example, between April and September 2008) due to the inability of generators to pass on basic costs. Where the price of coal is above the price of power, as was the case in much of 2008, the costs of coal alone (even excluding all other relevant costs) cannot be recovered by power generators. If the structure of Chinese power markets means that generators can barely support the cost of coal, supporting the cost of CCS is currently unthinkable absent major power sector reforms.

Figure 1 China's power market cannot bear the cost of coal



Source: Power price is Shanghai grid price as reported by Shanghai Development and Reform Commision. Coal price is Qinhuangdao price from Reuters. Note: Coal cost is expressed in terms of KWh and reflects the average efficiency of coal plants in China, assumed to be 2775 cal/Kwh. Numbers are indicative for the national market and may exclude some additional costs of coal and power generation.

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adjustment in May 2006. The system was only used twice since and failed to track the dramatic rise in coal prices in 2008.

[48] China Electricity Council, Office of Statistics and Information.

III.b Major CCS Deployment Would Create New Stress on the Coal Supply Chain

Many analysts and climate modelers have failed to consider that CCS costs are in fact not limited to the power sector—they would extend to the entire coal value chain. There is a significant reduction in the efficiency of power generation when CO_2 capture is added, as capture systems consume a lot of power: adding CO_2 capture reduces power generation efficiency by 20-30% (or 10-15 percentage points).[49] CCS thus requires an increase in coal consumption of around 20-25% to produce the same amount of electricity. We estimate that CCS at scale in China as prescribed by the IEA Blue scenario would demand approximately 200-300 million tons per year of additional coal production.[50] This level of incremental coal production above baseline targets would be accompanied by further stress on the coal supply chain that could itself threaten the paramount objective of maintaining cheap and reliable electricity. Infrastructure in the coal supply chain already struggles to keep pace with the growth in coal demand to fuel the economy; wide deployment of CCS would greatly exacerbate these strains. Beyond the obvious additional cost increases for generators, ramping up coal production to these levels would require new mining capacity, rail infrastructure, port expansions, and shipping capacity – investments on a massive scale. Appendix 1 considers in detail the costs throughout the coal supply chain that could be associated with a 200-300 million ton per year expansion in coal production and transport capacity to support the CCS deployment demands of the IEA Blue scenario. Costs would be well in excess of 100 million RMB (15 billion USD). If one were to include other environmental externalities of coal production and consumption, these numbers would be even higher.[51]

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[49] The loss in efficiency depends on the combustion technology used. For example, the efficiency loss is higher for post-combustion capture than for IGCC. See *IPCC Special Report on Carbon Dioxide Capture and Storage*, 2005 and *Carbon Capture and Storage: A Key Abatement Option*, IEA 2008.

[50] IEA Blue scenario projections of for CCS in China are 2 Gt CO_2 reductions by 2050, over 60% (or 1.2 Gt) of which come from the electricity sector. Our calculations show that achieving that scale will require 375 GW (gross) CCS-equipped coal capacity. Assumptions made for that calculation were: 50% gross efficiency; 5% auxiliary consumption; 10% efficiency loss due to capture; that is, 35% (50 – 5 – 10) net efficiency with capture; 85% capture rate; 0.8 plant load factor. Given that today's ~600 GW of coal capacity consumes 1.2 billion tonnes per year coal, an additional 25% for 375 GW (due to decreased efficiency) would represent an additional 190million tonnes of coal.

[51] In the report "The True Cost of Coal", Mao Yushi, Sheng Hong, Yang Fuqiang *et al*. report that when the environmental costs of coal are considered, along with the impact of price distortion caused by current regulations,

The costs of CCS, therefore, cannot be understood as limited to the power sector and instead permeate China's entire coal-based energy infrastructure. Because industry and infrastructure development is normally arranged in a five-year plan system, major infrastructure projects first are proposed, approved, and funded in the plan and then deployed into construction. Thus, ensuring the availability of coal supply for CCS at scale entails coordination of the entire energy industry and economic development system.

As China's central planners confront China's energy challenges, CCS investments have to be understood not only in terms of their own system-wide costs but also in terms of opportunity costs in foregone alternatives. China is now experiencing a boom in clean-energy development. Wind power has grown from 0.76 GW in 2004 to 13.24 GW in 2008. The Chinese government has a plan to reach 30GW of wind in 2020, which requires more than RMB 1 trillion (146 billion USD) in additional investment. Deployment of solar is planned to reach 10GW, and RMB 300 billion (43 billion USD) is estimated to be required in order to achieve that target. Nuclear is on track to account for 5% of the energy mix in 2020, and 750 billion RMB (109 billion USD) is required. CCS would likely come at the expense of some of these investments, a sober reality that is sure to weigh heavily on the minds of China's central planners[52] —especially given that these other alternatives enhance China's diversity of energy supply whereas CCS does not.

IV. The Path Forward: Paying for CCS in China

As we have illustrated, in their current form China's energy markets will be incapable of handling the high costs of CCS. Deployment of CCS in China, even at moderate scales, will thus require serious policy interventions and strong financial support. This leaves two broad options

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the total external costs of coal reached RMB 1745 billion in 2007, equal to 7.1 per cent of China's GDP for the same year.

[52] Su Wei, director general of the climate change unit at the NDRC made this point in an interview with Bloomberg on August 6th 2009, stating: "Carbon capture and storage, particularly for China, is not one of the priorities – the cost is an issue. If we spent the same money for CCS on energy efficiency and the development of renewables, it would generate larger climate-change benefits."

For more analysis on China's Clean Energy development, see *China's Clean Revolution*, The Climate Group 2008 and Wang, T and Watson, J, "China's Energy Transition – Pathways for Low Carbon Development", 2009.

for financing CCS at scale: direct financial support from the Chinese government or international financing mechanisms, likely through climate treaties or direct engagements.

The first option, domestic financial support for deploying CCS at scale, is highly unlikely given China's current energy strategy. China currently has few strategic or financial incentives to deploy CCS beyond the demonstration phase. While China is increasingly stressing sustainable development, this has not mean CO_2 mitigation thus far and economic development is still China's top priority. Spending on CO_2 mitigation through CCS is a diversion from that goal. Opportunity costs are high (see Section III.b above), and CCS will not measure up against other development and economic priorities. Further, investment in environmental controls at power plants is focused not on CO_2 mitigation but on abatement of local pollutants from coal combustion like SO_2 and NO_X that directly impact China's citizens on a daily basis. Controlling these pollutants also requires large investments, and China is moving ahead with the planning and deployment of these technologies. Support for CCS RD&D will continue because it aligns with longer-term Chinese objectives of energy security, but as the locus of domestic priorities lies elsewhere, new and much stronger incentives will be required for any type of CCS deployment at scale in the Chinese power market.

For the above reasons, international financial support will be needed if CCS deployment in China at scale is to become a reality in the near to medium term. Financial mechanisms under international climate agreements could conceivably be used to help support CCS projects in China. Debates are now underway that would attempt this by including CCS in the Clean Development Mechanism (CDM) under the UN's Kyoto protocol. Under such an arrangement firms would earn the market price of Certified Emissions Reductions (CERs) for every ton of CO_2 abated by a CCS project. The CDM could provide price levels of roughly €8-23 / ton (11 – 32 USD) of CO_2 for CCS investors.[53] While meaningful, these price levels are not sufficient when the marginal cost of abatement for CCS is on the order of \$50 to \$100 per ton of CO_2 (even without considering additional obstacles discussed above).[54,55] Another issue is that, for capital-

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[53] Based on historical data from the Reuters CER index. The DEC '08 and DEC '09 CER contracts have fluctuated between €7.48 and €22.85 (at the time of publication). Higher CER prices are possible and depend on a number of factors including market design and supply and demand.

[54] *IPCC Special Report on Carbon Dioxide Capture and Storage*, 2005 and *CO_2 Capture and Storage: A Key Abatement Option*, IEA 2008. See *Economic Instruments and Clean Coal Technologies,* IEA Clean Coal Center 2008 for further arguments that the CDM is insufficient to stimulate CCS investments.

[55] As discussed at several points earlier in the paper, the actual marginal cost will vary with the application, and the commercial and regulatory context for that technology. For example, if China builds IGCC/Poly generation for other

intensive projects like CCS, stability of revenue streams is critically important for the project's viability. Paying for the additional cost of CCS projects based solely on CERs will prove problematic on this front because of carbon price volatility.[56] Thus, CDM alone will not enable the widespread deployment of CCS. Funding CCS in China will require policy makers to rethink the design and application of international mechanisms for financing CO_2 mitigation.

International negotiations for a post-2012 climate agreement are currently focused on potential successors to the CDM. The EU has proposed "no lose" sectoral crediting mechanisms that, if properly designed, could be better equipped to stimulate CCS investment.[57] As currently envisioned for the power sector, the UN would establish a benchmark (likely based on emissions intensity), and provide carbon credits to sectors that perform better than the baseline.[58] CCS, which theoretically allows a very low emissions intensity, could be a potential beneficiary of such a policy. However, potential policies along these lines are still being shaped and are not yet clearly defined in such a way as to provide credible support for CCS.

Irrespective of the financial mechanism, those who argue that CCS in China must be a part of any climate solution need to soberly evaluate the scale of investment required. In the Chinese context, investments in CCS that would yield about 1.2 Gt/yr CO_2 emissions reductions by 2050 (IEA's ACT scenario) amount to a cumulative investment of $300-400 billion between 2030 and 2050, or an annual average investment of $25-30 billion. The total amount is even

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reasons then the marginal cost for CCS is much lower. On the other hand, if it does Greenfield power generation projects where IGCC w/CCS must compete with conventional coal then the marginal abatement cost is totally different (much higher).

[56] Hedging carbon price volatility would be possible with the existence of liquid, long-term derivatives markets for carbon. Thus far carbon policy has not been stable enough to provide these markets.

[57] See The UNFCC's "A text on other issues outlined in document FCCC/KP/AWG/2008/8" for the text of the EU's sectoral crediting proposal.

[58] There are a number of current proposals about the design and administration of a sectoral crediting system. For further information, see Meckling, J. and Chung. G.Y., "Sectoral Approaches to International Climate Policy", Discussion Paper 2009-02, Harvard Kennedy School, January 2009 and Schmidt, J., Helme, N., Lee, J., and Houdashelt, M., "Sector-based approach to the post-2012 climate change policy architecture", Climate Policy, August 2008 and Baron, R. and Ellis, J., "Sectoral Approaches and the Carbon Market", IEA 2009.

higher for the IEA's BLUE scenario for CCS in China, at $450-600 billion. These estimates exclude operating costs; including these can increase total costs by a further 50-100%.[59]

Thus, if deploying CCS in China is considered an imperative for climate policy, policy-makers will need to take note of the staggering scale of investment required and calibrate climate policy accordingly. If the scale of the offset mechanisms in the Kyoto Protocol and the US's Waxman-Markey legislation are any indicators of the likelihood and political viability of such a massive climate-based wealth transfer from the developed to the developing world, the precedent for funding CCS at scale through climate policy is not promising. In an optimistic scenario, CCS is included as a CDM methodology (or CDM's successor) and Waxman-Markey becomes law with a CCS methodology for international offsets. If this scenario occurs and 25% of these markets are dedicated to CCS funding, the total value of these funds would be around $7.2 billion annually.[60] This optimistic scenario still amounts to about 25% of the implied requirement for covering CCS in China ($25-30 billion annually) that is described above. Purely apart from the financial capacity of the developed world to support CCS in China, there is the question of the political viability of a program which could be seen by OECD voters as steering technology and jobs on a massive scale to an economic competitor.

Climate finance will certainly be critical for getting CCS off the ground in China, but given the political difficulties, policy strategies for international engagement will need to include additional types of CO_2 emissions reduction incentives. Cost-sharing agreements that are aligned with China's own incentives are likely to be the most tenable path forward in the near term. CCS is still critical for the abatement of emissions from coal, but in the face of daunting costs and risks, investors and policy makers should not ignore the full portfolio of options in the coal-fired power sector. Increasing the efficiency of Chinese coal combustion may represent a much greater opportunity for CO_2 mitigation in the near term. Because it naturally aligns with energy security incentives as discussed previously, improvement of combustion efficiency is already a top priority of Chinese policy and spending. Increasing the average efficiency of the Chinese coal fleet from its current average of 32% to the EU's average of 38% – a shift that

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[59] *CO_2 Capture and Storage: A Key Abatement Option*, IEA 2008. The IEA BLUE and ACT scenarios roughly call for 2 Gt and 1.2 Gt CO_2/year reductions in China through CCS by 2050.

[60] The following assumptions are used to generate this calculation which is purely indicative: (1) Average annual CER issuance will be 306 million, based on UNFCC estimates at http://cdm.unfccc.int/Statistics/Registration/AmountOfReductRegisteredProjPieChart.html (2) Waxman-Markey will maximize usage of international offsets at 1.5 billion per year (3) CER price is €15 (4) US offset price is the average of EPA's high and low scenarios in 2015: $15 (5) Euro to Dollar exchange rate is 1.413.

would be possible utilizing existing proven technologies – could represent a 20% reduction in emissions from China's power sector.[61] A critical step in this direction will indeed be to prove the viability of high-efficiency IGCC power generation as the GreenGen project hopes to do – an effort that could also build a foundation for later deployment of CCS.

V. Conclusions

The expansion of coal-fired power in China has propelled the country to its current position as the world's largest coal market and leading emitter of GHGs. As many analysts, policymakers, and academics have realized, any serious strategy for avoiding the worst consequences of climate change must therefore urgently confront emissions from Chinese coal combustion. Wide deployment of CCS technology is required to address this challenge. But without a careful assessment that takes into account the structure of Chinese energy markets and China's own priorities, the true potential for deployment of CCS in China will be miscalculated and climate policy will not address the coal challenge in a pragmatic way.

China is already undertaking CCS projects, both on its own and in international partnerships. But not all CCS projects are created equal, and the projects that are most viable support long-term priorities of the Chinese government: diversity of energy supply, domestic sourcing of energy, cheap and reliable electricity, and control of intellectual property for key technologies. Absent major changes in Chinese climate policy, it is these priorities that will continue to provide the driving logic for CCS in China. While these priorities have led to support of projects like Shenhua CTL and GreenGen, they do not automatically translate into support for wider CCS deployment.

Policy makers and observers need to understand that not all CCS projects are well matched to major sources of emissions in China, and as such China's CCS efforts offer disparate degrees of promise for CO_2 mitigation. CTL-CCS is likely to be the major source of sequestered CO_2 in China in the near term because China's incentives to add CCS to CTL projects for EOR are high and the risks are comparatively low. But the real climate benefits of CCS with CTL are minor, as CTL is not a major source of emissions in China. The key to reducing China's emissions from coal is applying CCS at power plants, where China has already made IGCC a priority and is charging ahead with GreenGen. While IGCC-CCS is likely to have the most

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[61] Indicative calculation based on emissions factors in Baruya, "Competitiveness of coal- fired power generation", IEA Clean Coal Center 2008.

chance of success among CCS for power options in China, deploying CCS in this context would still involve the formidable task of reinventing how power and chemicals are made in China.

Effective climate change policy requires both the vigorous promotion and careful calculation of CCS's role in Chinese power generation. Carbon finance must be applied to deploying CCS at scale in China. As the world approaches the end of the Kyoto Protocol in 2012 and crafts a new policy architecture for a global climate deal, international offset policy and potential US offset standards need to create methodologies that directly address CCS funding at scale. The more closely these policies are aligned with China's own incentives and the unique context of its coal and power markets, the better chance they have of realizing the optimal role for CCS in global climate efforts.

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Appendix 1: Costs Associated with Increasing Chinese Coal Production Capacity by 300 Million Tons to Support CCS Demands of IEA Blue Scenario

Increased costs would begin at the mine site. The average cost of extracting one ton of coal from underground in Shanxi is about RMB 115 (17 USD) in 2008 by modern mechanical systems, though it can as low as RMB 50 (7 USD) per ton by hand.[62] The best resources have already been extensively exploited, and the remaining coal is increasingly expensive to mine. Ramping up production by 300 million tonnes would require 340,000 additional workers and RMB 19 billion (2.8 billion USD) more investment in the fixed assets in the coal industry.[63]

Much of China's coal production is far from the coastal centers of industry that consume it, which requires a massive coal transportation infrastructure. Typical coal supply routes illustrate the complexity and challenge of moving nearly 3 billion tonnes of coal per year. For instance, in Shanxi Province, where about one fourth of China's coal is produced, most of the coal from the local mine is first transported by trucks to the local rail loading station. From that station the coal is transported 653 kilometers by the Da-Qin rail line to the major port Qinhuangdao on the Eastern coast. Qinhuangdao serves as a major trading hub that supplies industrial China with coal via maritime shipping supply routes to the south. This elaborate transport system of coal is used because the rail lines are so overburdened that it is cheaper to rail coal to Qinhuangdao and then ship it all the way to southern China on a boat then to rail it directly. The main railway line transporting coal from Shanxi to Qinhuangdao has already reached 340 million tons of coal carrying capacity in 2008. In 2010 it might reach 400 million tons at most with restructuring of the lines and upgrading of the capital stock. A second rail line with 200 million tons annual capacity from Lvliang in Shanxi to Qingdao port is under discussion, and about RMB 100 billion (14.6 billion USD) is needed to build such a new line. If one assumes 300 million tonnes of extra coal for CCS use, this means that it needs the equivalent of another Da-Qin rail line to transport added coal, which entails on the order of 133 billion RMB (19.4 billion USD) for rail alone given the scale of investment by the Lv-Liang line.

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[62] From interviews with local firms and industry experts.

[63] Calculated with data from China Coal Industry Yearbook 2006, based on inputs associated with new production that year. Fixed assets include facilities and equipment. In 2006, coal production was 2.33 billion tons, the total workforce in the coal industry was 2,657,230 and fixed assets investment was 147.9 billion RMB. Using linear growth as an indicative calculation, 300 million tons of additional coal requires about 340,000 additional workers and 19 billion RMB more investment.

If current rail to maritime routes are maintained, increased transport capacity would mean an expansion of the shipping fleet and domestic ports. Currently about 500 million tons of coal are moved by maritime trade in the Chinese market. Even moving an additional 150 million tons would require expanding the dry shipping fleet by around 1500 panamax vessels and expanding port capacity by 1/3 of current capacity. The Caofeidian port near Tangshan illustrates the scale of costs associated with additional port capacity. Construction of the port started in 2006 and targets 50 million tonnes in annual coal handling capacity in the first stage of development. It is estimated that RMB 15 billion (2.2 billion USD) in investment is required.[64]

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[64] From Caofeidian Port website.