JOHN L. THORNTON
China Center
at BROOKINGS

Key Opportunities for U.S.-China Cooperation on Coal and CCS

Kelly Sims Gallagher
Associate Professor of Energy and Environmental Policy,
The Fletcher School, Tufts University, and
Senior Research Associate,
Belfer Center for Science & International Affairs,
Harvard Kennedy School

December 2009

Table of Contents

Acknowlegements ii

Summary iii

Coal and CCS in China and the United States 1

The U.S. Context on Coal and CSS 3

The Chinese Context on CCS 6

Strategic Interest in Sino-U.S. Cooperation on Advanced Coal and CCS Technologies . . 10

Private-Sector Interest and Activity in Collaborative Projects 12

NGO and Academic Interest and Activity 13

Past Experience with Sino-Foreign Cooperation on CCS 14

Possible Options for More Substantial Cooperation on Coal and CCS 15

Unresolved Questions 17

References 18

Acknowledgements

The author wishes to gratefully acknowledge general support from the William and Flora Hewlett Foundation, BP Alternative Energy, and the Brookings Institution.

I appreciate the suggestions and comments provided to me by Dr. Liu Hengwei and Dr. Xuan Xiaowei, although I take full responsibility for the content and recommendations. Both are research fellows in the Energy, Climate, and Innovation (ECI) program at Fletcher, and affiliates of the Energy Technology Innovation Policy (ETIP) program at the Harvard Kennedy School. Dr. Xuan is also from the Development Research Center of the State Council.

Summary

This paper outlines the current situation regarding advanced coal and carbon capture and storage (CCS) in the United States and China. The strategic interest in cooperation on coal and CCS is explored, and then three options for collaboration are identified and discussed. None of the options are mutually exclusive. Remaining questions for discussion are provided at the end.

Coal and CCS in China and the United States

One of the most striking commonalities between China and the United States is that both countries are blessed with large coal reserves, and naturally, both rely heavily on coal for their primary energy supply. U.S. coal reserves are estimated at 243 billion tons (29% of world total), and Chinese at 115 billion tons (14% of world total). China's reserves-to-production ratio, however, is much shorter than that of the United States with only 41 years of currently-estimated economically recoverable coal compared with 224 years in the United States at current production rates (BP Statistical Review 2009). As the most abundant fossil energy resource in both countries, it is virtually certain that both will continue to rely heavily on coal due to its relatively low cost and the energy security benefits related to not having to import substantial foreign supplies of primary energy.

The utilization of coal will be increasingly limited by the climate change problem, however, unless advanced coal and carbon capture and storage (CCS) technologies can be developed, demonstrated, and rendered cost-effective within the next 5-15 years. Coal is the most polluting fuel from the standpoint of climate change; more carbon dioxide (CO_2) is polluted from coal than from any other fuel on a gram-per-gram basis. The climate change threat is very serious and may require dramatic cuts in *global* greenhouse-gas emissions in the next 10-20 years (see, for example, IPCC 2007, Anderson and Bows 2008, and Meinshausen et. al 2009). In short, both China and the United States will be required to dramatically reduce GHG emissions much sooner than either country would like if prevention of dangerous climate change is to be achieved.

The two main options for reducing the CO_2 emissions that result from burning coal are to increase the efficiency of coal use and to capture and sequester the CO_2 emitted from major coal-consuming industries. CCS is the process of separating CO_2 from industrial and power sources, transporting the CO_2 to a storage location, and injecting it into the storage site such as a depleted oil reservoir to prevent emission into the atmosphere (IPCC 2005, 3). CO_2 can be injected into depleted oil and gas reservoirs, deep saline aquifers, unmineable coal seams, deep-sea sediments, and elsewhere. In fact, CO_2 is routinely injected into oil fields for enhanced oil recovery (EOR) and, less frequently, for enhanced natural gas recovery.

Although some of the technologies associated with CCS are well established, the integrated process of capturing CO_2, compressing and transporting it, and storing it has not been done at a commercial scale in very many places around the world. And many capture technologies are still immature and expensive. There are, however, a few important existing integrated demonstrations of CCS, most notably the Weyburn project in Canada (EOR), In Salah in Algeria (gas field), and Sleipner in Norway (saline formation) (IPCC 2005, 33).

CO_2 can be captured from most large point sources (e.g. power plants, chemical production facilities). There are different kinds of carbon capture: *pre-combustion* usually refers to capturing CO_2 from coal gasification (such as polygeneration, coal-to-liquids, or IGCC) processes, *post-combustion* is associated with capturing carbon from the waste gases from conventional combustion (such as super-critical or ultra-super critical power plants), and *oxy-fuel combustion* is separation post oxygen-rich combustion. CCS is not restricted to coal, but it is often considered to be a good carbon mitigation option for coal since it is the only way to dramatically reduce the emissions from coal-consuming factories and power plants.

The cost of capturing carbon dioxide varies considerably and is quite uncertain. The conventional wisdom is that pre-combustion capture is cheaper, but recent progress in post-combustion capture technologies is challenging this conventional wisdom. A recent study based on U.S. project data indicated that the cost of first-of-a-kind plants based on coal gasification with carbon capture (not including compression and storage) could cost well over \$150/ton CO_2, with a range of \$120-180/ton CO_2 (Al-Juaied and Whitmore 2009). As more R&D is conducted and demonstrations built out, however, the costs could come down dramatically, estimated to eventually reach \$35-70/ton CO_2 with economies of scale and learning. If the CO_2 is used for EOR, the costs are further reduced because the CO_2 can be sold.

It is critical to note that the costs could be quite different in the Chinese context. A study utilizing Chinese data regarding the cost of IGCC vs. USC power plants (without carbon capture) indicated that the cost of constructing an IGCC plant in China is almost half the cost of constructing an equivalent plant in the United States (Zhao et. al 2008).[1] Labor costs, in particular, make the construction of major facilities less expensive in China. But, the costs associated with transport and storage of CO_2 in China could be higher than in the United States due to the lack of knowledge about the storage prospectivity, CO_2 pipeline availability, and so forth. Research is badly needed about the costs of CCS in the Chinese context, and data is very limited to answer this question.

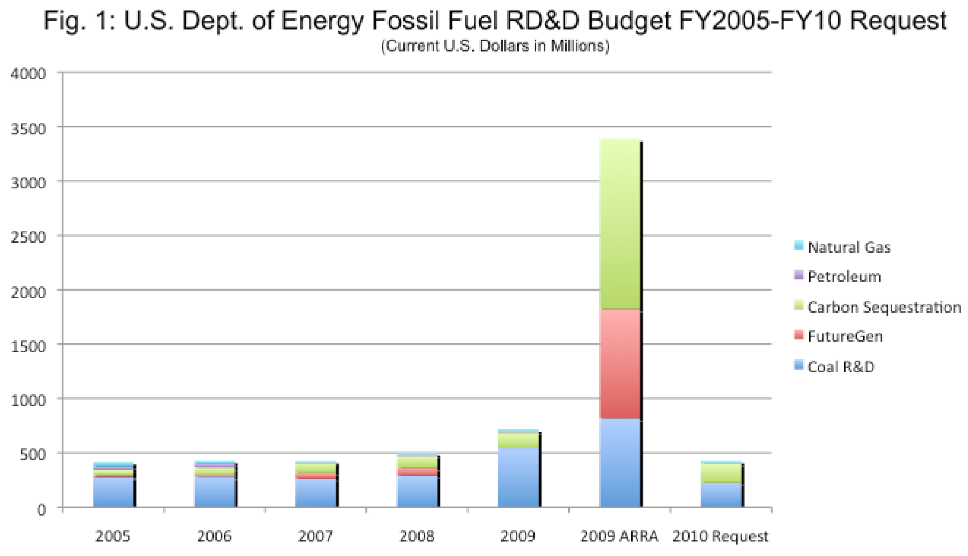
[1] In this study we determined that the capital costs of IGCC in China were between 7500-9000 yuan/kW (\$1010/kW-1300/kW at current exchange rates). This compares with estimates in the United States of nearly \$4000/kW for the Duke Edwardsport (assuming no capture).

The U.S. Context on Coal and CSS

The United States only uses half as much coal as China, but even so, coal accounts for about half of U.S. electricity generation. Coal is not used very much by U.S. industry, which tends to rely mainly on natural gas to fuel manufacturing facilities and for chemical production.

The United States has made a lot of progress in recent years on the research, development, and demonstration of CCS technologies. U.S. government funding for advanced coal and CCS got a huge boost in the economic stimulus package (see Figure 1). The most notable achievements include development and demonstration of cleaner coal technologies such as coal gasification, national mapping of prospective CO_2 storage sites, the development of regional sequestration partnerships, small-scale injections of CO_2 within the partnerships, and

FIGURE 1: U.S. Dept. of Energy Fossil Fuel RD&D Budget FY2005-FY10 Request



Data source: Gallagher, K.S. and L.D. Anadon, "DOE Budget Authority for Energy RD&D Database, June 12, 2009, available at http://belfercenter.ksg.harvard.edu/publication/19119/

planning for FutureGen. The Clean Coal Power Initiative (CCPI) supports large-scale demonstration projects together with private sector. There are three government-supported IGCC demonstration plants operating in the United States.[2]

There are seven regional carbon sequestration partnerships in the United States, supported by the U.S. Department of Energy. This initiative, announced in 2003, is intended to develop the technological capabilities and infrastructure for carbon storage. During the first phase of the program, the Partnerships characterized the potential for CO_2 storage in deep oil-, gas-, coal-, and saline-bearing formations, and as a result, a Carbon Sequestration Atlas of the United States and Canada, last updated in May 2009, is available. In the program's second phase, the Partnerships confirmed and validated regional sequestration opportunities through small-scale geological storage tests. In Phase III, the Regional Carbon Sequestration Partnerships are working to implement nine large-scale sequestration projects that will demonstrate the long-term, effective, and safe storage of CO_2 in the major geologic formations throughout the United States and portions of Canada. These injections are expected to begin at some sites as early as Spring 2010 (DOE 2009).

FutureGen was announced by President Bush in 2003, but then halted in late early 2008 ostensibly due to rising costs. The Obama Administration has resurrected consideration of the project. The latest plans call for it to be constructed in Matoon, Illinois as a coal gasification coupled with CCS facility at a 275 MW scale. The public-private partnership project will initially capture 60 percent of the CO_2 emissions with a goal of eventually capturing 90 percent. Huaneng joined the FutureGen Industrial Alliance. Funding for FutureGen was added to the stimulus package as can be seen in Figure 1, and in September 2009, a new cooperative agreement was signed between the Industrial Alliance and DOE to begin feasibility studies. Much work has also begun on resolving some of the policy questions, such as how to design a regulatory system for CCS, how to manage liability issues, and how to overcome the relatively high costs of these first-of-a-kind plants.

Despite all the progress on the research, development, and demonstration of advanced coal and CCS, the United States still has much work to do to encourage the actual deployment of these technologies in the marketplace. If the U.S. Congress passes legislation to create a cap-and-trade program for GHG's, a price will effectively be imposed on the emission of CO_2, which will make it more economical to capture and store CO_2 from coal-fired power plants and factories. Still, the likely prevailing price of CO_2 is not going to be high enough to create a strong enough incentive in the short term.

The Clean Energy and Security Act of 2009 (otherwise known as the Waxman-Markey bill), which passed the U.S. House of Representatives in mid-2009, was modeled to produce a carbon price in the range of $17-22/ton CO_2. Thus, a clear gap can be identified between the cost of CCS and the incentive created by a politically feasible carbon price in the United States. Thus, complementary policies will certainly be needed. Included in the CESA were other provisions to support CCS. On provision, known previously as the Boucher bill, allows utilities to impose a small fee on fossil fuel electricity generation to support secure and stable funding for large-scale CCS demonstration projects. This fee would be assessed for 10 years, and could generate approximately $1.0 billion per year to support CCS demonstration projects. CESA also instructs the U.S. EPA to create regulations for CCS. The EPA is also authorized to provide grants to cover the incremental costs of CCS for plants larger than 250 MW. As a regulatory backstop, the bill also creates new performance standards for new coal-fired power plants. Beginning in January 2015, a new

[2] Wabash River Coal Gasification Repowering Project, 262 MWe – coal/petcoke (1995-present), Tampa Electric Polk Power Station, 250 MWe – coal/petcoke (1996-present), and Valero Delaware City Refinery's Delaware Clean Energy Cogeneration Project 160 MWe & steam – petcoke (2002-present).

emissions performance standard of 1,100 lbs CO_2/MWh would be in effect, equivalent to a carbon capture rate of approximately 50 percent.

If Congress fails to pass the cap-and-trade bill, alternative policies are essential. A number of policy instruments have already been passed in energy legislation and the stimulus bill for advanced coal and CCS technologies, including loan guarantees and investment and production tax credits. These incentives appear to have been effective in galvanizing private sector interest in commercializing coal with CCS, but the fact of the matter is that no commercial plants with CCS yet exist in the United States, although the Duke Energy Edwardsport plant in Indiana is scheduled to come on line in 2012 and many more are slated for construction (see Table 1).

Aside from the Clean Energy and Security Act (which has yet to pass the Senate as of this writing), the other main deployment policies are contained in several other pieces of legislation. The Energy Policy Act of 2005 contained loan guarantees for "advanced" energy technologies, including coal gasification technologies. Because the loan guarantee program needed to be created, this policy was slow to take effect. EPAct 2005 also included Investment Tax Credits for IGCC projects, which were eligible for a 20 percent investment tax credit, other advanced coal-based projects that produce electricity were eligible for a 15 percent credit, and industrial gasification projects were eligible for a 20 percent credit. The American Recovery and Reinvestment Act of 2009 appropriated significantly more additional funds for loan guarantees and tax credits, especially for projects that incorporated CCS. At the state level, there are tax credits, loan guarantees, low-interest loans, sales tax exemptions, and bond funds in most coal-producing states.

Table 1: A Sampling of Active IGCC Projects in the United States

PROJECT	LOCATION	DETAILS	DATE IN SERVICE
Duke Edwardsport	Indiana	Coal, 630MWe, GE gasifier, CO_2 capture study	2012
Kemper County IGCC	Mississippi	Coal, 600MWe, KBR gasifier, 65% capture w/ EOR	2013
Mesaba Energy Project	Minnesota	Coal, 600MWe, E-gasifier, capture ready	?
Taylorville Energy Center	Illinois	Coal, 630MWe, GE gasifier, CO_2 capture planned	2014
Hydrogen Energy	California	Petcoke, 390MWe, GE gasifier, 2 Mt/a capture	2014
Cash Creek Generation	Kentucky	Coal, 630MWe, GE gasifier, EOR	2012
Great Lakes Energy	Michigan	Coal, 250MWe, ConocoPhillips, 1.25 Mt/a EOR	2012
Good Springs IGCC	Pennsylvania	Coal, 270MWe, China TPRI, CCS planned	?
Somerset Gasification Retrofit	Massachusetts	Coal/Biomass, 120MWe, WPC	2011

Adapted from Gary Stiegel, NETL, DOE, 2009

The Chinese Context on CCS

Tremendous progress has been achieved in China in developing advanced coal technologies, most notably coal gasification and ultra-supercritical technologies. Both technologies are much more efficient than conventional subcritical coal combustion technologies. Coal gasification permits "polygeneration"—the production of both synthetic gas and various chemical feedstocks, and China's progress on polygeneration is advanced, especially in the chemicals sector. The Chinese government approved China's first IGCC plant with a planned CCS component, the Huaneng Green-Gen project, in 2009. The first IGCC project was Yankuang, discussed later.

In China, the attitude towards CCS has been more tentative and ambiguous than in the United States, probably because of a classic chicken-and-egg problem—why should China invest in an expensive carbon mitigation technology if China has not committed to a climate policy regime? But, China cannot commit to a climate policy regime if it has not determined whether or not it can reconcile continued use of energy with GHG emissions reductions while undergoing rapid industrialization and urbanization. In addition, it is difficult, if not impossible for China to make a unilateral commitment in the absence of a global GHG agreement. The ambiguous attitude has led to China making much less progress developing and demonstrating CCS technologies than in the United States. Still, China has made tremendous progress on advanced coal technologies that may enable carbon capture in the future. Indeed, Chinese capabilities in advanced coal technologies, particularly gasification-based technologies, are becoming so strong that Chinese research institutes and companies are beginning to export their technologies to the United States. Two recent cases include the licensing of the East China University of Science & Technology (ECUST) petroleum coke gasification technology to U.S. refiner Valero Energy Corporation, and the Thermal Power Research Institute's agreement with U.S. firm FutureFuels to provide gasification technology.[3]

Currently, 80 percent of China's GHG emissions come from coal use. Power generation dominates China's CO_2 emissions and is expected to account for about 50% of total emissions between 2005 and 2030. Industry accounts for more than a quarter of Chinese CO_2 emissions—iron and steel accounted for 8%, non-metallic minerals for 6%, and chemicals and petrochemicals for 4% of CO_2 emissions in 2005 (Liu and Gallagher 2009). CCS is perhaps the only energy technology with no "co-benefits" associated

[3] See http://icct.ecust.edu.cn/liste.php?id=17&newsid=288 and http://www.businesswire.com/portal/site/home/permalink/?ndmViewId=news_view&newsId=20090917005440&newsLang=en

with using the technology, such as improvements in human health, reduced acid rain and improved energy efficiency; in other words, there is no reason to invest in the technology unless the goal is to reduce CO_2 emissions. For this reason, the Chinese government appears to have ranked it last among other GHG mitigation technological priorities including advanced coal, energy efficiency, nuclear, and renewables. To date, the Chinese government appears to have decided to let developed countries take the lead on CCS RD&D, but this "wait and see" strategy could harm China in the long-run because technological laggardness on CCS technologies will cause China to become increasingly reliant on foreigners for a technology that will undoubtedly be needed in China.

Many Chinese researchers and academics have come to realize the potential importance of the technology, but there is relatively small RD&D funding available for CCS in China, notwithstanding the creation of new RD&D programs in both the Ministry of Science and Technology (MOST) and the Chinese Academy of Sciences (CAS) in the last year. Compared with the situation in the United States, it is fair to say that the advancement of CCS knowledge in China has just begun. There is no detailed national carbon storage assessment and the new CCS RD&D programs appear to be mostly confined to pre-combustion capture research. Most Chinese firms are not familiar with CCS technology, but there are a few notable exceptions including Huaneng, Dongguan, Shenhua, and a few others as can be seen in Tables 2 and 3.

In June 2008, MOST announced that it would support a research program on CCS. MOST's research funds for CCS are managed by the 973 basic science division, not the 863 energy division, though cooperation between the two will increasingly be necessary. The 973 program has just begun supporting research on carbon storage, funding CNPC to conduct a CO_2 EOR experiment in Jilin, for example. Because the 863 program is devoted to "high-tech" applied research and development, CCS does not currently qualify for the 863 program because it is considered too far from commercialization. Also, the Administrative Centre for China's Agenda 21 (ACCA21), which is housed in MOST, appears to manage much of the international cooperation activity for CCS.

The Chinese Academy of Sciences has also begun supporting some research on CCS. Again, most of the new funds are for pre-combustion capture technologies. But, CAS was the first to support research on carbon storage, mainly within CAS's Institute of Soil and Rock Mechanics in Wuhan. The National Natural Science Foundation is also supporting some CCS research.

MOST has supported three IGCC and two co-production projects to the point where they are now awaiting approval from the National Development and Reform Commission (NDRC). The first project was approved on May 21, 2009—the GreenGen IGCC project.

In 1999, the Chinese government approved an IGCC demonstration project in Yantai, Shandong Province with an intended installed capacity of 300-400 MW. However, the project did not proceed as planned, largely due to the high cost of foreign technologies.[4] In 1998, the Chinese Academy of Sciences Institute of Engineering Thermophysics started to develop coal-based co-production technologies. Yankuang took advantage of this technology and has built the first coal gasification-based co-production system, which went into operation in April 2006. During the 11th Five-Year Plan, several IGCC plants were planned. The following table shows the active IGCC projects in China now.[5]

[4] In addition, the Yantai IGCC project was developed by the former State Electricity Company, which was divided into 5 power groups and 2 grid groups due to the reform in 2003. After that, no one was clearly put in charge of the project.

[5] China started research on IGCC technology in the 1970s. In 1996, U.S. DOE and the National Science and Technology Commission of China organized an U.S.-Sino IGCC Expert Report, in which the authors made clear that the combination of IGCC and co-production would promote the development of IGCC.

Table 2. Active IGCC Projects in China

Active Projects	Location	Feedstock	MWe	Gasifier Vendor	CO_2 Capture
China Huaneng IGCC Project (GreenGen)	Tianjin	Coal	250	TPRI	STUDY
Dongguan IGCC (repowered)*	Dongguan, Guangdong	Coal	2×60	CAS	STUDY
Dongguan IGCC*	Dongguan, Guangdong	Coal	4×200	CAS	STUDY
Huadian Banshan IGCC*	Hangzhou, Zhejiang	Coal	200	ECUST	STUDY
China Power Investment Corporation IGCC*	Langfang, Hebei	Coal	2×400	N/A	8% EOR
*Awaiting approval from Chinese government					

In addition to these IGCC and other polygeneration coal gasification projects, there are two major coal-to-liquids plants planned. Shenhua, the largest coal company in China is building the largest CTL plant in the world in Ordos, Inner Mongolia. When this CTL plant is finished, it will also be the largest point-source of carbon dioxide in the world. The first phase of the plant went on trial in December 2008. The second trial run of the plant began in September 2009 and was scheduled to run for 1000 hours. If expanded, the coal liquefaction facility would be able to contribute 5 million tons of liquid fuel annually. Shenhua completed a prefeasibility study for CCS at the end of 2008, and is currently conducting a feasibility study, and thus may add a CCS component.[6] The main conclusion of the pre-feasibility study was that there was great potential for carbon storage in the Ordos basin. EOR appears to be the more economical option in theory, but the practical problem of having to construct long distance CO_2 pipelines to the east makes such a prospect unlikely. As an example of Sino-U.S. cooperation, West Virginia University and Lawrence Livermore National Laboratory (LLNL) were involved in the pre-feasibility study.

Table 3. Active CTL Projects in China

Active Projects	Location	Feedstock	Firms Involved	Gasifier Vendor	CO_2 Capture
CTL Plant	Ordos, Inner Mongolia	Coal	Shenhua	Shell	Feasibility study
CTL Plant (currently suspended)	Ningxia Hui	Coal	Shenhua, Sasol, Foster Wheeler, Wuhuan Engineering	Shell	Plan to capture CO_2

[6] Communication with Shenhua official, May 2009.

China Huaneng Group conducted the first CO_2 capture demonstration project in China in a thermal power plant in Beijing (3000 tons CO_2/year), starting in 2008 in a cooperative project with the Australians. This was a post-combustion capture project. Huaneng is constructing a second post-combustion capture demonstration project in Shanghai (100,000 tons CO_2/year).

There are at least six serious projects that are sufficiently well developed that they could serve as the basis for a large-scale integrated demonstration project. The projects can be divided into two main categories: IGCC/Polygeneration with CCS, and CTL with CCS (see Table 1 and Table 2). The Huaneng GreenGen project has a planned capture and EOR component in the second phase.

Strategic Interest in Sino-U.S. Cooperation on Advanced Coal and CCS Technologies

Cooperation on CCS is in both countries' interest because CCS is a technology that could permit both countries to continue using their vast coal reserves while drastically reducing emissions. Cooperation enables both China and the United States to share costs, share risk, increase the speed of unit cost reductions, and accelerate learning about and acceptance of these technologies. In particular, the costs of commercial-scale demonstration are high, so cooperation among U.S. and Chinese firms and governments on a couple of large carbon storage demonstration projects could greatly reduce the costs of these projects to all parties.

To the extent that firms are involved in the cooperative efforts, they may establish relationships that better enable them to profit in both countries' markets in the future. To the extent that researchers and academics are involved, they may gain knowledge and insights about technological developments, opportunities and constraints in China, and developments in Chinese policy. NGO participation can help build public confidence in the technology.

Although this paper has focused primarily on activities in the power sector, it is important to note that CCS is appropriate for most large stationary sources of CO_2 emissions because those sources usually have high capital costs and economies of scale (Liu and Gallagher 2009). The cost of capture from these sources depends on the concentration of CO_2 in the flue gas stream. Costs of capture fall with higher concentrations of CO_2.

CCS cooperation deserves high priority in the U.S.-China bilateral relationship because both countries rely heavily on coal for their primary energy supply, and partially because of the coal intensity of their economies, the two countries account for nearly half of global greenhouse gas (GHG) emissions.

To "act in time" on the climate change threat, it is imperative to immediately accelerate research, development, and demonstration on CCS because it will take time to bring down the currently high costs of CCS through additional R&D, and it will also take time to demonstrate the technology at scale for long enough to provide sufficient confidence that the technology is viable (or, conversely, determine that it is infeasible) (Gallagher 2009).

Given the rapid pace of construction of new coal-fired power plants, coal-to-liquid (CTL) plants, and manufacturing facilities in China (and the less rapid but still considerable planned growth in coal-fired power plants in the United States), combined with the unlikelihood that either country will prematurely retire plants and factories being built today, the sooner the viability of the technology can be determined, the sooner both can avoid locking into an even more carbon-intensive economy. CCS, if effective, might allow both countries to transition to a low-carbon economy without discarding capital investments that have been made in electricity infrastructure. In 2007, there were 2,211 power plants that emitted at least 1 million tons of CO_2 a year: 559 in China, and 520 in the United States (Schrag 2009).

Private-Sector Interest and Activity in Collaborative Projects

Several U.S. firms (or multinational companies with U.S. subsidiaries) have indicated interest in collaborating with Chinese firms on advanced coal and CCS projects. In August 2009, Duke Energy signed a Memorandum of Understanding with Huaneng for developing renewable and clean energy technologies. In September 2009, Southern Company and KBR Inc. agreed to license their Transport Integrated Gasification (TRIG) IGCC technology to the Beijing Guoneng Yinghua Clean Energy Engineering Co. for use in the Dongguan Tianming Electric Power IGCC project. Conversely, as already mentioned, both TPRI and East China University for Science & Technology have recently signed licensing agreements for exporting their coal gasification technologies to FutureFuels and Valero, respectively. Peabody Coal is an investor in the GreenGen project. Conversely, Huaneng joined the FutureGen Industrial Alliance before it was cancelled, and although it is still part of the Industrial Alliance, it may not remain a partner.

NGO and Academic Interest and Activity

There has been fairly limited NGO and academic interest and activity related to CCS in China. The Energy Technology Innovation Policy program at Harvard worked for 7 years with MOST and CAS on technology policy related to advanced coal and CCS through joint workshops, hosting of researchers at Harvard, and collaborative research with various partners in China. This work will now mainly continue through the Energy, Climate, and Innovation (ECI) program at The Fletcher School at Tufts University, in partnership with Harvard. The ECI program is developing a MOU with the Development Research Center of the State Council to study policies for a low-carbon economy, including policies for advanced coal and CCS. The World Resources Institute is partnering with Tsinghua, funded as part of the Asia Pacific Partnership (APP) to assess regulatory and liability issues. Stanford University's Global Climate and Energy Project initiated an international collaboration with the University of Southern California (USC), Peking University (PKU) and China University of Geosciences at Wuhan (CUG) to research large-scale sequestration of carbon dioxide in saline aquifers in China in August 2009.

Past Experience with Sino-Foreign Cooperation on CCS

U.S. – China CCS Cooperation

The United States government has not been involved in any major CCS project with China. A number of MOUs have been agreed to in the past as part of the U.S.-China Fossil Protocol and the Asia Pacific Partnership, and relatively small research projects have been conducted under those auspices. The United States initiated the international Carbon Storage Leadership Forum (CSLF), which has proved to be a successful venue for sharing data and information, and China has been involved in the CSLF.

As with much Sino-U.S. energy cooperation in the past, the tendency has been to sign memorandums of understanding, but not implement those agreements with vigor, providing adequate funding for projects, and ensuring that they are brought to completion. A frank discussion of why cooperation projects have not been more fruitful so far is certainly warranted.

Nonetheless, the Chinese and U.S. governments agreed in July 2009 to form a new Joint Clean Energy Research Center, and CCS is one of the work areas identified for the center. This center will be managed by the U.S. DOE, China's MOST and Bureau of Energy Administration (BEA). Together, the two countries pledged $15 million for initial activities, split equally.

EU and Australian CCS Cooperation with China

There are two European agreements with China to cooperate on CCS. One is called Cooperation Action within CCS China-EU (COACH), and one is the Near Zero Emissions Initiative (NZEC). The COACH project was initiated by the EU, and has 20 project partners, mainly comprised of industry participants from the two countries. The NZEC initiative was launched by the UK in 2007. Both offer general frameworks for collaboration The COACH project intended to actually proceed with a demonstration project in later years, and there was effort to make the GreenGen project become the COACH demonstration project. NZEC will also somehow support the CCS demonstration at GreenGen. Last year, Australia's research institute CSIRO established a demonstration project for post-combustion capture (3000 tonnes/year) at a pilot plant in Beijing owned by Huaneng, together with the Thermal Power Research Institute, as previously mentioned.

Possible Options for More Substantial Cooperation on Coal and CCS

Option 1 – Large Scale CCS Demonstration Plants

Establish two large-scale demonstration plants that include CCS—one in China and one in the United States. These could be pre-combustion, post-combustion, or oxyfuel capture projects, or they could utilize an existing available stream of CO_2 and concentrate on demonstrating storage.

In terms of costs, CTL plants might be the cheapest because the costs of capture are significantly lower in CTL configurations than they are for IGCC or post-combustion. CTL-CCS projects would also be significant projects environmentally because they are very carbon intensive. Power projects might have more significance for future application, however, and if combined with EOR, would be less expensive than without.

The two projects could take the shape of international public-private partnerships, or direct joint ventures could be formed between Chinese and U.S. firms, with some kind of subsidized support from the governments. No matter what public-private mechanism or structure is chosen for the cooperation, a critical condition of the cooperation should be that the data from the project be transparently available to the public. Both countries, their firms, and their research entities should be able to learn from both projects. While both governments should contribute financially, private-sector firms could likely bear the main costs, especially if the U.S. firms can take advantage of the loan guarantees and tax credit instruments in recent U.S. legislation.

The advantages of doing one or more full-blown CCS demonstration project is that its existence would clearly make a tremendous contribution to the advancement of knowledge about the viability of CCS in both countries, and internationally. By sharing knowledge from two projects, at least twice the knowledge is gained, and probably more.

The main disadvantage is that such a major projects would undoubtedly be complex to negotiate, especially since it is desirable to structure the project as a public-private partnership. This would involve determining the levels and degrees of transparency among partners and the general public, allocating IP, and contributions to the cost of the project. This hurdle, while considerable, should certainly not be considered insurmountable. Indeed, complex arrangements are negotiated every day in the private sector.

Such demonstration projects would be relatively more expensive than the other options outlined here, but much *less* expensive than if the projects were done by each country alone. The exact costs can only be determined by choice of *type* of project (pre-combustion, post, oxy-fuel, CTL), and *arrangement* of the partnership.

Option 2 – Collaborative R&D on Pre-Commercial Technologies

Collaborative R&D on pre-commercial technologies for IGCC, Co-Production, and CCS would share enable both countries to share costs, share risk, and gain knowledge. An agreement could be set up to share R&D facilities and utilize each other's laboratories. Innovative catalysts, absorbents and adsorbents for syngas conversion and CO_2 capture could be tested in each other's labs. Researchers would benefit from sending product samples to each other for testing. Also, the adaptability of certain advanced technologies could be explored. Will different technologies be useful and suitable in the other country's context? There is some evidence that certain gasifiers are not working well in China, for example.

The advantages for Option 2 are that this collaborative research may not impose any significant new costs because both countries are already planning to devote portions of their energy RD&D budgets to these topics, so sharing information or directly collaborating on research would not be much more expensive. If true cost-sharing is achieved, cost reductions could even be achieved. This option has already been initiated as part of the new U.S.-China Clean Energy Research Center, but no details yet exist.

Option 3 – Policy Research on CCS Strategy for Deployment, and Education

It would be a mistake to only focus on the technology "push" side of the equation without also considering what would be required to "pull" CCS technologies into the market. Research on appropriate demonstration and early deployment policies is needed for both countries. Which policy instruments are most effective and in which combination? Policy research on the legal issues would also be valuable. It appears that the legal barriers may be greater in the United States than in China, but this hypothesis should be explored with empirical study.

Studies on the suitability of policy harmonization would also be helpful because harmonized policies could lead to more standardization, reduced costs for industry, and faster deployment. Finally, a study of barriers to technology transfer for IGCC, co-production, and CCS would be valuable. We need to better understand the nature of the barriers in order to design policies to overcome them. Assertions are frequently made that IP protection is a big concern, but this is not so clear. If it isn't, what is the main constraint? Cost? We need more evidence. It was also asserted that "re-demonstration" of technologies is sometimes needed in China to assure that foreign technologies will work in China. If so, why would there be a need for re-demonstration and how might that have helped in the past?

With respect to education, it would clearly be useful to support student and faculty fellowships for exchanges. Development of a workforce in both countries that is trained to work on the technical and policy dimensions of advanced coal and CCS is badly needed. Greater support for students and faculty to do research in each other's countries would therefore be useful.

Workshops sponsored by government and academia have proven to be useful mechanisms for sharing knowledge and stimulating planning in new directions. The CAS-MOST-Harvard annual workshops held since 2002, for example, have become an important annual platform for communication and exchange for the energy technology policy communities in both countries.

Unresolved Questions

1. What are the budgets for cooperation?

2. Why has past U.S.-China energy-technology cooperation generally not gone beyond MOUs, and how could CCS be different?

3. How many projects should be pursued?

4. How to determine cost-sharing arrangements, deliverables, and timetable?

5. How to structure international public-private partnerships?

6. How to share information and data?

7. How does CCS fit into the other priorities in the relationship?

References

Al-Juaied, Mohammed and Adam Whitmore, 2009. "Realistic Costs of Carbon Capture." Discussion Paper 2009-08, Energy Technology Innovation Research Group, Belfer Center for Science and International Affairs, Harvard Kennedy School, July.

Anderson, K. and A. Bows 2008, "Reframing the Climate Change Challenge in Light of Post-2000 Emission Trends," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 366, No. 1882: 3863-82.

BP Statistical Review of World Energy 2009, BP Group, London.

Gallagher, K.S. 2009, "Acting in Time on Climate Change", Chapter 2 in Gallagher, K.S. (ed) *Acting in Time on Energy Policy*, Brookings Institution Press.

IPCC 2005, Carbon Dioxide Capture and Storage, Intergovernmental Panel on Climate Change Special Report, edited by B. Metz, O. Davidson, H. de Coninck, M. Loos, and L. Meyer, Cambridge University Press.

IPCC 2007, Meinshausen, M., Meinshausen, N, Hare, W., Raper, S.C.B. Frieler, K., Kutti, R., Frame, D.J., and M.R. Allen 2009, "Greenhouse-gas emission targets for limiting global warming to 2°C," *Nature* 458(7242): 1158-1163.

Liu, Hengwei and K.S. Gallagher 2009, "Catalyzing Strategic Transformation to a Low Carbon Economy: A CCS Roadmap for China," *Energy Policy* (accepted, in press).

Schrag, Daniel P. 2009, "Making Carbon Capture and Storage Work," in Gallagher, K.S. (ed) *Acting in Time on Energy Policy,* Brookings Institution Press.

Stiegel, Gary 2009, "DOE's Technology Policy for RD&D of IGCC and CCS," National Energy Technology Laboratory, U.S. Department of Energy, Presentation, Harvard University, April.

Zhao, Lifeng, Xiao, Yunhan, Gallagher, Kelly Sims, Wang, Bo and Xu Xiang 2008, "Economic Assessment of Deploying Advanced Coal Power Technologies in the Chinese Context," *Energy Policy*, Vol. 36, No. 7: 2709-2718.

John L. Thornton China Center • December 2009

BROOKINGS
The Brookings Institution
1775 Massachusetts Ave., NW
Washington, D.C. 20036
brookings.edu